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bio-dynamics incorporated

human factors | physiological monitoring | bionics

N65 16932

(ACCESSION NUMBER)	(THRU)
208	1
(PAGES)	(CODE)
CR 60635	04
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

GPO PRICE $ ______

OTS PRICE(S) $ ______

Hard copy (HC) $6.00

Microfiche (MF) 1.25

one main street, cambridge, massachusetts

UNPUBLISHED PRELIMINARY DATA

Final Report
Contract No. NASw-570

Study of the Transferral of Space Technology to Biomedicine

submitted to

Grants and Research Contracts
Code SC
Office of Space Sciences
National Aeronautics and Space Administration
Washington 25, D. C.

by

Bio-Dynamics, Inc.
One Main Street
Cambridge, Massachusetts

February 21, 1964

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I. INTRODUCTION

A. Contract Objectives

This report describes the results of an investigation of the transfer of innovations arising from the Nation's space effort to the fields of medicine. Emphasis was placed on those areas dealing with the acquisition, measurement, processing, and interpreting of physiological data, and upon related medical-mechnical and medical-electronic techniques. To determine the "spin-off" effects of space research and technology on these areas of medical and biological research, relevant socio-economic and historical factors were reviewed, and these factors related to the amount of transfer which has been observed.

B. Justification of Interest

Research programs dealing with the biological aspects of space flight, physiological monitoring and selection of astronauts, miniaturization of electronic devices, improved reliability of equipment, and new materials technology represent significant expenditures of space program funds. The likelihood of finding any regular transference of techniques or knowledge from aerospace activities to the non-space related fields of medicine depends mainly upon the extent to which space and non-space needs and goals are consonant. We believe that in the above mentioned areas of activity there are such matchings. The existence of mutual needs and goals is not sufficient, however, to insure transfer from one field to another. Such transfer must be continually stimulated and encouraged, primarily through the dissemination of information regarding research results. The responsibility for actively promoting the rapid dissemination and adoption of government supported research results or innovations which potentially may produce significant benefits to the public resides at the highest level. However, such activities are not without risks. In some cases the government may find itself in the position of thereby destroying the initiative for industry sponsored research in the same areas, or of unintentionally favoring one private profit-making enterprise over another due to chance factors (such as geographic location, personal contacts, etc.). This is not likely to happen in the transfer of information or innovations into the life sciences, since the bulk of research is already government or institutionally supported. The humanitarian appeal of active efforts to advance the medical sciences lends support to activities by government agencies in promoting the dissemination and adoption of their innovations in this area.

Communication of information between disciplines, or even from mission-oriented research to more general applications within the same discipline, is a highly complicated process. Adoption of new techniques by medical practitioners with responsibilities for patients is highly dependent on the method of communication, the communicator and the nature of the innovation. To effectively reach the various medical specialties may require that NASA utilize communications channels other than those presently routinely used. For this reason it is important to assess the effectiveness of present NASA dissemination techniques and develop recommendations for improvements if appropriate.

C. Summary

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Examples of interdisciplinary innovation transfer, results of interviews and questionaires, and a literature review have been used to develop a series of recommendations for improving the transfer of space technology innovations into the life sciences. A number of specific instances of transfer have been documented, but the general impact of aerospace stimulation of entire fields of endeavor appears to be a more significant effect. NASA procedures for disseminating information have been compared to those of several other agencies and the implications of the differences discussed. It is concluded that there is evidence of a "spin-off" of space technology into biomedicine, that the rate of transfer can be improved, and that active efforts to produce transfer are justifiable.

Author

II COMMUNICATIONS IN THE LIFE SCIENCES

A. Communications Channels

The diffusion of innovations within the life sciences is effected through the use of a great variety of formal and informal channels of communication. These channels are identified in the following paragraphs, and a discussion of their effectiveness will be presented in later sections of this report.

1. Formal Communications

Formal information communications include publications in scientific journals, presentations at technical meetings or symposia, scientific books, technical reports, and formal instruction (short courses, refresher courses, etc.). The effectiveness of formal publications is enhanced by abstracting and review articles or services, dissemination of reprints (often through industrial sources if manufacturing of the innovation is underway), citations in the popular news media, and through a variety of other formal and informal intermediate communications. Formal communications generally have the disadvantage of reaching only a very restricted audience until a considerable time period has elapsed since the original research finding was made. In the field of psychology it has been determined that on the average 18 months elapse from the time a research project starts until work reaches a report stage (1). An additional 18 months generally elapses before a journal publication appears, then 12 more pass before the article appears in Psychological Abstracts, and another eight months pass before the article is cited in the Annual Review of Psychology. Published programs from scientific meetings may greatly encourage informal communications among interested scientists and the information originator, but such programs are often not widely disseminated. Technical reports released to ASTIA and subsequently to OTS may diffuse out to the general public in four or five months, but ASTIA and OTS abstract or reference sources are not universally read by non-governmental life scientists. Among those medical practitioners contacted in the interview phase of the present study, none regularly used ASTIA or OTS services. Formal communications channels can produce rapid dissemination of information within the originator's own subspecialty, but with the exception of certain interdisciplinary journals and symposia, may not reach scientists in other subspecialties, even within the same academic discipline, until a year or more has elapsed.

2. Informal Communications

Informal information communications include conversations, letters, phone calls, review of progress reports or grant requests, citations in popular news media and informal seminar gatherings. Conversations may include those with the originator of the information as well as those with individuals whose role is solely that of transmission or conveyance. In certain specialties within the life sciences great emphasis is placed on personal contact communications, as evidenced by survey results, reported in subsequent sections of this report.

Informal communications can produce rapid diffusion of research findings among small groups of researchers, but are not reliable in this respect. Ability and opportunity to informally communicate information from the originator to the user varies widely among individual scientists. Professional information conveyors, such as the detail men retained by pharmaceutical firms, effectively communicate with some physicians, but not with others. Salesmen or applications engineers representing biomedical instrumentation manufacturers do not reach many potential users, and have varying success in communicating with life scientists once a contact is made. Informal communications are valuable adjuncts to formal communications, both in guiding the user to the appropriate formal reports and in expanding the information formally presented. Informal communications frequently result from contacts made at formal meetings and are therefore at least partially dependent on the travel funds available to a scientist. It is reported that many scientists "maintain closer professional contact with scientists hundreds or thousands of miles away than they do with the institutional colleagues with whom they have lunch" (2).

B. Problems in Biomedical Communication

The rapid expansion in life science research and the resulting enlargement of knowledge has severely taxed existing communications channels for diffusing new knowledge and innovations to the potential users. Much of this research has been government supported. For example, financial support from the Federal

Government for medical and health-related research alone was expected to exceed one billion dollars in 1963 (3). Communication of research results, and particularly those of government sponsored investigators has become of great concern to the Federal Government. This concern was highlighted by a recent statement by the late President, John F. Kennedy:

> "One of the major opportunities for enhancing the effectiveness of our national scientific and technical effort and the efficiency of Government management of research and development lies in the improvement of our ability to communicate information about current research efforts and the results of past efforts". (4)

Considerable progress has been made in improving the formal dissemination of government sponsored research results (see Section IV of this report), but much remains to be accomplished. Scientific journals represent the primary storehouse of technical knowledge, and through such encouragements as extension of the page-cost allowances to certain research grants additional life-science publications are appearing. However, effectiveness of scientific journals in interdisciplinary communication is limited, and the time delay between submission and publication of a paper may range from three months to two years. Bibliographies of research reports compiled by the Office of Technical Services and review articles or bibliographies issued by various government agencies may serve to alert scientists to the existence of unpublished technical reports which they might not otherwise discover, but again the time delay and the restricted audience receiving announcement of these reports are limiting factors.

It is impractical for any scientist to attempt to review all of the published biological science papers, the yearly volume now exceeds 150,000 articles and is increasing at about ten percent annually. The number of journals containing articles related to medicine is also rapidly expanding. In 1958 the National Library of Medicine had approximately 13,000 such journals (5).

Research is underway on many fronts to improve scientific documentation procedures. For example, the Institute for the Advancement of Medical Communication, under the sponsorship of the National Institutes of Health and other agencies is studying "the metabolism of biomedical information from generation to utilization, and of medical practitioners' use of available information" (6). The National Medical Library is perfecting MEDLARS, a computer based storage and retrieval system developed by General Electric, which will regularly produce bibliographies in fairly broad areas, provide specialized bibliographies, and organize and print out Index Medicus. Biological Abstracts recently introduced a new listing method in an attempt to meet the specialized information needs of individual scientists. The new system is a permuted word indexing known as KWIC (Keyword-in Context) which alphabetically lists under each heading those titles of articles which contain the keyword (7). However, for the individual scientist information retrieval will remain a problem in the immediate future.

Information dissemination and retrieval problems differ from specialty to specialty, and may be particularly severe between disciplines. To obtain relevant information from another technology for the solution of problems within a particular field may require that the scientist utilize unfamiliar reference tools. Communication of new developments is more highly organized in some fields than in others, particularly in those undergoing a rapid expansion of knowledge. In general, scientists working in areas at the fringe of science have little trouble keeping up to date. For example, according to a recent article (8) molecular biologists keep abreast of developments in their field by means of personal communication. Such a system provides speedy dissemination, the capacity for immediate evaluation, and rapid feedback of relevant or conflicting information. However, reliance upon personal communications is obviously impractical in large fields of technology where the vast number of individuals involved and the amount of information generated is such that "a more serious difficulty exists, one that has been described as an information crisis" (8).

As new fields emerge and the number of scientists working in the area increase, formal communications media appear in response to the needs for information dissemination. The number of individuals working in the areas of bioelectronics and bioastronautics has expanded beyond the level where personal communications are adequate for keeping abreast of developments. For example, the 1963 Bioelectronic Directory lists nearly 1300 senior individuals who reported that they were working in the field of bioelectronics. The developing literature in these fields is of concern to the present study since space technology innovations relevant to non-space related biomedical research or practices will usually be communicated through this literature. Product description periodicals (such as Medical Electronics News), technical journals (such as Medical Electronics and Biological Engineering or IEEE Transactions on Bio-Medical Electronics), conferences (such as the Annual Conference on Engineering in Medicine and Biology), and numerous symposia presently serve as specialized formal communication channels in bioelectronics. These channels supplement the more general instrumentation, electronics, and life science journals by carrying a higher density of information specific to the interdisciplinary aspects of bioelectronics. Unfortunately a large proportion of the scientists working in medical areas do not regularly use, or are not aware of this interdisciplinary literature, nor of the abstract and indexing sources which cover it.

Although the number of individuals practicing medicine and the rate of medical information generation are so large as to preclude relying on unorganized personal communications as the major information dissemination technique, little is known concerning techniques to improve personal interchange. The necessity for personal interchange in effective medical communication has often been repeated, and the stated reasons are difficult to challenge.

> "The practice of medicine is in large measure still an art--much more so than engineering or architecture. An art is better learned from participation, observation and discussion than from the best planned exposition or formal presentation" (2).

Personal communication is widely used by pharmaceutical firms in promoting their products within hospitals and medical teaching institutions to disseminate new developments and techniques, and even within government health agencies for the rapid dissemination of ideas and information. Among those personal communication techniques which have been successfully employed by the National Institutes of Health (NIH) are the Study Sections, Review Committees, and

Special Advisory Groups. These groups, formed of leading authorities in their field and representing institutions throughout the country, "form a unique framework of communication in the bio-medical science community" and are "one of the most vital and productive of the informal communications process" (2). However, members of these groups are not necessarily exposed to the innovations resulting from research efforts supported by NASA or by other agencies outside of the NIH.

The interdisciplinary approach to problems in the life sciences has been increasingly evident in recent years. Effectiveness of this team effort has been dramatically demonstrated in a number of instances, even to the point of establishing new academic disciplines to exploit specific combinations of backgrounds (for example, biophysics, biochemistry, health physics, and bio-medical engineering). These interdisciplinary groups may help to bridge the communications gaps between the physical, engineering, and biological sciences. At present, the scientist not connected with a large institution may have little or no contact with persons able to discuss problems in his field and relate them to advances in another field. In particular, there is a continuing need to reach the life scientist operating within a narrow specialty, discover the problems for which he needs solutions, and communicate to him the relevant new technology in other fields. If this must be accomplished through informal communications channels, then additional knowledge will be needed regarding techniques for the development and encouragement of personal interchange.

C. A Survey of Communications Habits of Selected Bio-Medical Scientists

A group of 86 bio-medical scientists in the Boston area were interviewed to ascertain their communications habits, the needs for innovations or improvements within their specialties, and what recent developments within their specialties were regarded as the most significant. Those persons interviewed are tabulated by discipline in Table 1, and by institutional association in Table 2. The communications habits and preferences for information sources expressed by the representatives of the various academic disciplines are described in the following paragraphs. Needs for innovations and significant recent developments in these specialties are described in Section V of this report.

1. Biochemistry - Seven biochemists were interviewed, four of whom were medical doctors, one was a doctor of veterinary medicine, and two were Ph. D.'s in biochemistry. This group expressed a strong preference for technical publication of their own work as a means of disseminating research results, but regarded personal contacts as the best source of new ideas to apply in their work. They regarded their field as one in which developments were occurring at a rapid pace and that the up-to-the-minute nature of personal contacts was essential to keeping track of current developments. As a group, they made extensive

TABLE 1

Summary of Fields or Specialties Obtained During Interviews of 86 Medical Scientists*

Anatomy	Neurology
Anesthesiology	Neurophysiology
Audiology	Neurosurgery
Bacteriology & Immunology	Obstetrics & Gynecology
Bio-Engineering	Occupational Hygiene
Biophysics	Opthalmology
Cardiac Surgery	Optometry
Cardiology	Oral Pathology
Cardiovascular Surgery	Orthodontics
Dental Medicine	Orthopedic Surgery
Dermatology	Pathology
Ear, Nose, & Throat Medicine	Periodontology
Ecology	Pharmacology
Gastroenterology	Physics
Genetics	Physiology
Genito-Urological Surgery	Pulmonary Physiology
Geriatrics	Radiobiology
Hematology	Renal Physiology
Information Retrieval	Respiratory Physiology
Legal Medicine	Sanitary Engineering
Mathematical Biology	Teaching (Medical)
Medical Administration	Thoracic Surgery
	Veterinary Medicine

*86 individuals from 23 institutions or non-profit organizations, five industrial or profit-making concerns, one state government department, two self-employed. Included are individuals representing 47 fields or specialties.

TABLE 2

Summary of Interviewed Medical Scientists
and Their Fields of Work

Institution	ORIENTATION				No.
	Research	Clinical	Teaching	Administration	
Angell Memorial	Pathology				1
Astra Pharmaceuticals	Pharmacol.				1
Boston City Hospital	Cardiol.		1	1	1
Beth Israel Hospital	Cardiol. 2 Pulmonal. Hematol. Oral Pathol.		2 1 1	2 1	2
Boston University	Sea Mammal Ecol.		1		1
Boston University School of Medicine		Thoracic Surgery			1
Childrens' Hosp. Med. Center	Cardiovasc. Surg. Genetics		1		1 1
Flow Corp.	Bioeng.				1
Forsyth Dental Clinic	Orthodontics			Director	2

TABLE 2 (continued b)

Institution	ORIENTATION				
	Research	Clinical	Teaching	Administration	No.
		Legal Med.			1
Harvard Univ. Med. Sch.	Biophysics 3				3
	Bacteriol & Immunol. 2		1		2
	Anat. & Radiol.		1		1
	Pathol.		1		1
	Physiol.		1		1
	Cardiac Surg.				1
Harvard University	Appl. Physics		1		1
	Cyclotron				1
Harvard Sch. Dental Med.	Periodontol.			Assist. Dean	1
Harvard Univ. Sch. Public Health	Cardiol. Respirat.		1	1	1
	Physiol. 2		2		2
IBM	Radiobiol.			1	1
Inst. Stomatological Res.	Biophysics 2			Director	1
Lincoln Labs.	Bioeng.				1
Mass. College Optometry				Dean	1
Mason Res. Insti.	Director			1	1
Mass. Eye & Ear Infirmary	Ophthalmol.				1

TABLE 2 (continued c)

Institution	ORIENTATION				
	Research	Clinical	Teaching	Administration	No.
Mass. Gen. Hospital	Neurol.				1
	Neurosurg. 2	1			2
	Biophysics 6			1	6
	Anesthesia 3	1	1	1	3
	Cryosurg.	1			1
		Gastro-enterology			1
	Orthoped. Surg.				1
	Cardiol.				1
	Dermatol.				1
MIT	Appl. Bio-physics		1		1
	Neurophysiol. 2		1		2
	Info. Retreival				1
	Gastrc enterology			1	1
MITRE	Biophysics				1
Overholt Thoracic Clinic	Thoracic Surg.				1
		Director	1	1	1
Peter Bent Brigham Hosp.	Pulmonal.		1		1
		Genito-Urol. Surg.			1
	Math. Biol.				1
	Kidney				1
	Anesthesia	1	1	1	1
	Cardiol.	1	1		1

TABLE 2 (continued d)

Institution	ORIENTATION				
	Research	Clinical	Teaching	Administration	No.
Peter Bent Brigham Hosp.	Geriatrics	1			1
Private Practice		Orthopedic Surg. 2			2
		ENT			1
	Optometry	1			1
Sanborn				Bioeng.	1
St. Elizabeth's Hosp.	Hematol.				1
Commonwealth Mass.				Occupational Hygiene	1
				Sanitary Eng.	1
Tufts Univ. Sch. Medicine		Obstetrics & Gynecol.	1		1
V.A. Hospital	Audiology	1			1
Worcester Found. for Exp. Biol.	Biophysics				1

use of abstracting journals and cross-indexing sources in accessing information sources. The group was sharply divided among those who actively sought out new innovation information from industrial literature, equipment exhibits, and demonstrations, as opposed to those who sought to avoid such contacts as much as possible.

2. Biophysics - Ten biophysicists were interviewed, three of whom were medical doctors, five Ph. D. 's, one DDS, and one MS. This group was unanimous in the expression of the dominance of personal contact as an information exchange channel. They tended to downgrade technical meetings as an important communications channel, although symposia were regarded somewhat more favorable than the convention ype of meeting. Journals were frequently regarded as important sources of information, as was course instruction offered in area institutions.

3. Radiology - Six radiologists were interviewed, only two of whom were medical doctors... This group was heavily dependent on industrial literature or reports, government reports, and technical journals as sources of information. They favored journal publication of their own research findings as a means of dissemination. Most of those interviewed expressed a need for better access to government documents, reflecting the dominant role of government sponsorship in radiation research. One interviewee expressed great dissatisfaction with accessibility of NASA documents in this field.

4. Bioengineering - Seven bioengineers were interviewed, five of whom have doctorates in their academic disciplines. These individuals tended to disseminate

information primarily on the basis of personal contacts, much of this in the course of providing consulting assistance to life scientists. As a group they did not express a preference for scientific journals over meetings as information sources, although several who were research oriented did. Several of the group were employed by industry or by government agencies and utilized in-house and ASTIA documents extensively. In general the bioengineers serve as disseminators of new engineering and physical science technology into the life sciences. They transfer concepts, methods, and materials from one application to another and frequently review new advances in technologies for possible application to specific biomedical problems.

5. Bacteriology and Immunology - One bacteriologist and one immunologist were interviewed. Both regarded contacts within their institutions (universities), rapid-publication technical journals such as Science, interdisciplinary journals such as Scientific American, and texts as valuable sources of new information. Both of these individuals considered large meetings as of little value to their communication needs.

6. Pharmacology - One pharmacologist was interviewed, the director of research of a drug company. This individual regularly reviews a large number of technical journals and attends a large number of scientific meetings. Information obtained through these sources is often further disseminated through his own company literature.

7. Cardiology - Six cardiologists were interviewed. All of these physicians hire full or part-time engineering assistance to aid in their research or practice.

All of the cardiologists maintain close industrial contacts (biomedical instrumentation firms) or close contact with engineering groups in local universities. Personal contacts with colleagues were regarded as more important than formal meetings or journals as sources of information. Informal seminars in which representatives from a biomedical instrument manufacturing company lectured were also mentioned as a valuable interdisciplinary information source by cardiologists from one institution.

8. Cardiac Surgery - Three cardiac surgeons were interviewed, two of whom are practicing surgeons, the third concentrating in research. The practicing surgeons regarded meetings as most informative and technical journals second in importance. The research surgeon depended primarily on journals and personal contacts as communications channels.

9. Hematology - Two hematologists were interviewed. Both considered personal contacts as their primary source of new ideas, journals next in importance, and meetings less effective. Both regarded technical publication of their own research results as the most effective means of dissemination.

10. Thoracic Surgery - Three thoracic surgeons were included in the survey, one primarily involved in research, another primarily teaching, and the third a practicing thoracic surgeon. All three rely on personal contacts as information sources, but only the academician and the researcher utilized journals as a source of detailed information or as a channel for communication of their own ideas. The practicing surgeon transmits information via informal hospital seminars or case presentations, as does the academician.

11. Pulmonary Physiology - Four physicians specializing in pulmonary physiology were included in the survey sample. Three of the four are supported by full time engineering assistance in their research and practice, and all maintain close contacts with outside university and industrial consultants. The researchers utilized journals extensively as a communication channel, while the clinicians tended to favor technical meetings for this purpose.

12. Physiology - Three physician physiologists were interviewed, all were connected with academic institutions. Primary emphasis was on lectures and seminars within the institution as communication channels, although the library facilities were also regarded as a valuable information source. Technical meetings were not regarded as very effective information sources.

13. Anesthesiology - Two chiefs of anesthesia services in teaching hospitals and two researchers in anesthesia departments were interviewed. The former reported that in the course of reviewing manuscripts or pre-prints, and performing administrative duties associated with the research projects performed by their staff they are exposed to progress in their field in many forms. In this capacity they also function as information transmitters, disseminating new knowledge among representatives of government supporting agencies, industry, colleagues, and residents. The researchers utilize technical journals extensively as communication channels.

14. Renal Physiology - One physician performing research on kidney function, pathology, and treatment reported that extensive communication activities were utilized in his department of a large teaching hospital. All members of the department give periodic seminars on their work, have a compulsory journal reading list, participate in grand rounds, and have frequent guest lecturers speak to the department. In addition, formal coursework at nearby universities is encouraged. This individual regarded technical meetings as a very inefficient use of time.

15. Genito-Urinary (GU) Surgeon - One G. U. Surgeon was interviewed. This individual communicates his skills and progress via technical meetings. He also spends a large portion of his time in small conference groups composed of colleagues and residents.

16. Neurology - Three neurologists reported that contacts with industrial representatives for information on equipment advances were essential. Personal contacts with colleagues, and frequent visitors from foreign lands provide more information than might otherwise be gained at technical meetings and also allow rapid dissemination of new information. New texts were also utilized, but scientific journals were not regarded as particularly efficient transmission channels.

17. Public Health Engineering - Two public health officers were interviewed, one primarily involved in occupational health, the other in sanitary engineering.

The former utilizes personal contacts extensively as a communications channel, while the latter relies heavily on technical meetings and journals and industrial literature as communications channels. Both individuals extensively use government documents and reports for new information in their field.

18. Legal Medicine - One forensic pathologist reported that personal contacts and literature from instrument manufacturers were his principle communications channels.

19. Audiology - One audiologist reported that technical journals, formal course-work at universities, and government reports were his principle sources of new information.

20. Geriatrics - One physician specializing in geriatric services described his communications channels as including interdisciplinary seminars attended by (physicians, nurses, psychologists, psychiatrists, and social workers), local level technical meetings, and several technical journals.

21. Ecology - One ecologist connected with a university was interviewed. Visits to other institutions, discussions with colleagues and technical journals were reported as the most effective communication channels.

22. Opthalmology - Two opthalmologists were interviewed. Both were associated with a teaching institution and considered personal contacts and seminars as important information sources. Technical meetings and journals were not regularly used for this purpose.

23. Optometry - Two optometrists reported that they rely heavily on industrial innovations in their field, and on interdisciplinary meetings for information exchange.

24. Ear, Nose and Throat (ENT) - One ENT clinician was interviewed. This individual reported that technical meetings were the principle communications channel for him since demonstrations at these meetings are a highly effective means of communication.

25. Orthopedic Surgery - Three orthopedic surgeons were interviewed. All made regular use of journal articles (from The Journal of Bone and Joint Surgery in particular), hospital seminars and personal contacts. Only one mentioned contacts with instrumentation manufacturers as an important source of information.

26. Gastroenterology - Two gastroenterologists reported that periodic review of instrumentation journals and personal contacts with colleagues and industrial representatives were their principle sources of information on endoscopic innovations.

27. Obstetrics and Gynecology - One physician specializing in OB-GYN was interviewed. This individual reported that it is difficult to obtain useful information relative to new electronic instruments for his specialty. The equipment is as complex as that used by the cardiologists, but engineering assistance is not generally available. Communications are largely restricted to personal

contacts.

28. Veterinary Pathology - One veterinary pathologist reported that personal contacts with individuals in government agencies and teaching/research institutions together with numerous technical journals constitute his communications channels.

29. Dentistry - Two dental pathologists, one orthodontist, one periodontist, and one dental surgeon were interviewed. The pathologists rely on personal contacts and a small number of technical journals as communication channels. The orthodontist frequently consults with engineers at a local university for new information. He also reviews technical journals in a number of diverse fields for additional knowledge. The periodontist reported that technical journals are his principle communications channel. The dental surgeon relies heavily on technical meetings, but primarily as a source of new personal contacts.

In summary, certain specialties that rely on engineering and the physical sciences for innovations are reasonably well supplied with transmitters of interdisciplinary information. Individuals in these specialties (such as cardiology, respiratory physiology, cardiac surgery, and neurology) use a variety of communication channels, and communicate extensively. In general, researchers and clinicians depend heavily on personal communications and regard this channel as the most important source of ideas. However, as a secondary source the researchers tend to rely on technical journals, while this is true for only a few clinicians (such as orthopedic surgeons). On the other hand, many clinicians regard technical meetings as important information sources (the demonstrations at the meetings being considered highly effective), while the researchers find them to be a very inefficient communication channel. Few of the individuals interviewed made use of government ~~documents or were~~ even aware of aerospace research which might be of value in their research or practice.

III. DISSEMINATION OF INNOVATION

A. Model of Innovation Dissemination

Technological change has become an inherent part of the Western way of life. The consumer, the industrialist, the scientist, the physician expect that the way in which they perform their work today will seem antiquated a generation from now. Almost as universally accepted as the inevitability of change is the recognition that not all sectors of the economy advance uniformly. The modern farmer routinely raises food with tools and procedures that hardly existed a generation ago; yet most fishermen have been relatively unaffected by the mid-century technological revolution. Even within certain sectors of the economy, such as manufacturing, there are vast differences in utilization of the newer sciences and technology. Within the practice of medicine, perhaps the most complex of human activities certain specialties have only begun to benefit from the great store of physical science and technology which has been built in the last twenty years, while other specialties (such as radiology, for example) have been revolutionized during the same period.

The fact that these discrepancies exist is of great interest to the social scientist as a "natural" phenomena; they are of urgent concern to those leaders in the professions, industry and government who believe that efficient use of technology, and effective guidance of the sciences which support it constitute a major goal of any nation. Furthermore, the gaps which now exist between what is available and what is being used may widen, since the rate of development of new technical information appears to be constantly accelerating.

These interests and concerns have lead to the development of "models" of technology utilization by economists and sociologists. Our objective in this study has been to construct a description of the present status of space technology utilization in biomedicine, where it might be a few years from now, and to recommend a program of NASA-OTU directed activities which will aid in achieving a high utilization. Hence, a review of the literature on innovation dissemination was undertaken to become familiar with the analytical methodologies which have been developed.

Our review of the literature indicates that investigation of the process of innovation introduction and spread has typically been addressed to either broad "total economy" studies (see for example reference 10) or to identification of the dissemination process for particular innovations in particular contexts. As far as we know there has been no scientific description of that effect of new technology termed by Solo as a "widening (of) the horizon for business inventiveness and creative innovation" (11). There has also been relatively little work done on developing ways of measuring the national activity which produces innovation - science. While Dedijer (12) concludes that the U. S., Britain and the USSR are spending roughly the same percentage (2.3 - 2.8%) of their GNP on science, and doubling their funding every four to five years, he points out the unreliability of present methods of making such assessments.

The studies of dissemination of particular innovations in particular contexts seem to divide into two groups. Those which describe the dissemination process as obeying certain laws of probability, and those which deal with the sociological mechanism of dissemination, describing the key factors and their respective roles in the spread of a new idea or thing.

The work of Professor Mansfield represents the probablistic approach to the dissemination of innovations (13). His study of the diffusion of specific major technological innovations contributes models which serve as reasonably accurate predictors of a firm's behavior with respect to such innovations. Mansfield has suggested that a firm's "response" to the appearance of a new piece of equipment is analogous, in a general sense, to the stimulus-response patterns defined by experimental psychologists studying animal and human behavior. In papers published by the Cowles Foundation and the National Science Foundation, Mansfield describes the acceptance of important new devices in four industries (bituminous coal, iron and steel, railroad, and brewing). He sought to determine whether data from firms in these industries would permit development of "rules" for predicting innovation acceptance on the basis of the following characteristics of the firm and the particular innovations. Rate, growth of the firm, the firm's profit level and profit trend, the age of its management, its liquidity, the extent of its "commitment" to R & D, the age of equipment which would be replaced by the innovation, extent of competitive pressure in the industry, the number of competitive firms using the innovation, the size of the investment required by the innovation, the expected profitability of the innovation, and the size of the firm (13, 14, 15, 16). Mansfield found that, statistically, the liklihood that a firm would adopt an innovation was high, 1) if the required investments were relatively low, 2) if it was expected to return a good profit, 3) if several other firms had already successfully adopted it, and 4) if the firm were a large one. None of the other characteristics of the user or of the innovation seemed to be statistically significantly related to the probability of acceptance of an innovation. Grilischer (17), found that farmers exhibit an economically rational behavior in adapting use of hybrid corn. The date of origin of use of hybrid corn is an area, the rate of build-up in its use, and the eventual proportion of hybrid/non-hybrid corn use was a function of the expected profitability of use of the innovation.

The second approach to desciption of innovation acceptance - identifying the sociological factors and the roles they play in the process - is represented in the studies reported by Somers (18) and Hildebrand (19). Hildebrand finds that the agricultural innovator - one who says he's willing to be the first in his community to try something - is different from the average farmer in most of the following respects:

-higher income

-either markedly higher, or lower net worth

-greater use of hired labor

-rents part of the land he farms

-younger

-more education

-not a full time farmer

-experienced in incorporating innovation.

The personal and economic stimuli to innovation are, of course, countered by barriers to innovation, barriers which are based on facts or ignorance, communication inadequacy, and some important "irrational" human considerations. "Rational" barriers will be described more fully in following sections, but it must be kept in mind that "obviously" beneficial innovations are frequently resisted by such unmeasurable forces as reluctance to "throw away" a still-useful device of procedure, pressures by or on behalf of workers who must acquire new skills if the innovation is adopted, and the lack of confidence of management in its own ability to direct the productivity of the innovation (20).

There are few markets in which efficiency of introduction and dissemination of innovation are as important as they are for drugs and medication. The National Science Foundation's survey of industrial research and development expenditures disclosed that the drug industry's annual investment in research was above any other industry, and rising (in the years 1958-60) faster than industry as a whole (21). This large and expanding scientific effort is producing new drug products at an apparently ever-increasing rate. Hence, the more the drug producer knows about the diffusion of change in clinical medicine (i.e., the more accurate his "model" of the drug adoption process) the better able is he to efficiently introduce his innovation.

Coleman and Menzel of Columbia University published what has become a classic study of new drug dissemination in 1959 (22). They studied the spread in use of a new drug as a social phenomenon, disregarding the objective merits of the drug. The importance of social contact among physicians as an agent in widening use of the drug was clear - especially in the early stages of the drug's introduction. Certain medical specialties were quicker than others in making use of the drug* (pediatricians being more innovative in this case than internists, for example). Other studies of the drug acceptance phenomena include Menzel's (23) which led to the conclusion that the doctor's attitude toward change in general (i.e. wheter innovation was inherently good or not) was related to the nature of his doctor-patient relation. The innovative physician, for example, seemed to more regularly repond to patient's feelings and requests.

Rogers (24) has published a recent review of more than 500 studies relating to innovation dissemination. He makes the observation that: "although the diffusion of most desirable innovations requires a considerable lag, there is a certain inevitability in their diffusion". The lags he cites as representative

*The drug was one that might be used by a practitioner in any specialty.

are 14 years for adoption of hybrid corn, and 50 years for adoption (by all schools) of new educational practices; Mansfield (15) found that it generally took more than 10 years for all major firms in an industry to accept an important innovation. There are many different ways in which the elements of the diffusion process can be classified: Rogers suggests dividing the phenomena into:

a. Innovations

b. Communication

c. The social or economic system context

d. The time during which the diffusion process is operating.

Inasmuch as the purpose of the present review is to establish a conceptual groundwork for the analysis of space technology transfer and for development of recommendations as to how to increase its efficiency, the following action-oriented categorization appears more appropriate:

1. Nature and probable benefits, including advantages-disadvantages of the innovation.

2. Actions of the introducer of the innovation
   a. "Packaging" of the innovation
   b. Communication content, method and timing.

3. Characteristics (including attitudes) of potential and actual acceptors of the innovation, and their actions with respect to the innovation.

4. Barriers

5. Stimuli

6. Methods of measurement and analysis of the process.

Following are some of the less obvious current experimental findings and hypotheses regarding these factors in spread of innovation:

1. Nature and probable benefits, including advantages-disadvantages of the innovation. *

   The innovation that is compatible with current practices and culture will be more readily accepted.

   The innovation must fill a need which the potential acceptor has already recognized.

2. Actions of the introducers and disseminators of innovations.

   a. "Packaging"

   In the case where the form of innovation can be modified to fit the market, it should be so modified to reflect the consideration cited above. Often, in the case of space technology, the "packaging" effort will take place in planning the communication, so that the innovation is described in terms that will render it most acceptable.

   b. Communications

   The communicator typically is operating in an "open loop" mode; he can control the quality, intensity, frequency, etc. of the communication, but he cannot control the tuning or sensitivity of the information receiver nor can he even readily observe the effect of his

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*Hereafter the term innovation will be used to encompass "the development, invention, discovery, modification or new use of a device, process, material, system, or technique" (NASA Form 66, Rev. Jun 62).

communication.

c. As the process of innovation acceptance proceeds from awareness to adoption, the form of communication needed also changes. In the early stages, "impersonal" communication media (articles, etc.) are most effective, but in the trial and evaluation stage, personal communication is of vital importance. With regard to major technological innovations, there is little evidence that lack of initial knowledge about innovations is a significant factor in the delay of their adoption (24). However, the communicability of an innovation is an important factor affecting the rate and extent of adoption. If the innovation provides the user with a "topic of conversation" and is widely discussed, its diffusion will be accelerated.

Personal communication by an outside "innovation agent" (e.g., and OTU representative) is more important to early than to late adopters of an innovation.

A vital role of communication by the innovation generator is simply to lower the threshhold to change; i.e. communicate the idea that change is at least not undesirable. In doing so, the innovation generator must consider the potential acceptor's image of him in planning the communication. For example, NASA's image to the life science researcher or clinician is simply not the same as that of NIH. The most difficult communication problem is from one community into another which has few congruent problems. attitudes, etc. (for example NASA supported metallurgists communicating with dental surgeons). Communication must be bilaterial in innovation "packaging", introduction and dissemination. The originator must receive the needs of the potential user and the constraints of his "environment" as well as transmitting information.

In a community which has a steady or very slowly changing pattern of communication channels for new ideas, (e.g. microbiologists) the innovation source must decide to commit itself to a long range program of feeding innovation, so that the users come to view the agency as a regular source of new ideas, and to (as a goal) solicit innovations from the agency. In promoting utilization of science and technology developed under the space program, OTU must use communication to push and pull. That is, in some instances NASA must deal directly with potential users of its knowledge (scientists in re-scientific findings), and in other cases it must educate the target community about the availability of technology which must be "converted" (by a manufacturer, or a clinical evaluation group, etc.) before the innovation can be useful.

3. Characteristics of potential and actual acceptors of the innovation, and their action with respect to the innovation.

A useful (although not yet detached) model of the innovation dissemination process is based on learning theory. In this view the potential user is seen as the subject of a "conditioning" operation in which accepting behavior is to be rewarded by the direct effects of the innovation, or by indirect positive reinforcement of his colleagues. In most cases the curve of number-of-adopters in time assumes the shape of a normal distribution. Rogers (24) characterized the groups who constitute this distribution as:

1) Innovators (venturesome)
2) Early adopters (respectful of [illegible] actively soliciting information about the new)
3) Early majority (deliberate)
4) Late majority (skeptical)
5) Laggards (traditional)

Rogers has also characterized the process through which each user goes as: awareness, interest, evaluation, trial and adoption.

Some innovations (in particular the large ones) require acceptance by a group, each member of which may have different characteristics and motives.

While the instrument-maker has always been a necessary ancillary to the life scientist, his contribution has generally been sporadic. The emergence of the physical sciences, mathematics and engineering acting in professional collaboration with the life sciences is recent, and not yet widespread. There is still a great gap in lang age, methodology and goods which the outside "seller" of new physical science and technology must recognize.

Clinical medicine seems much more hierarchically structured (by seniority) than its supporting life sciences.

An outstanding innovator and student of the new technology dissemination process, J. R. Pierce of Bell Laboratories, drew a clear distinction between the motives of the scientist and the technologist in accepting change. The intent of his observation would not be distorted, we believe, by substituting the term clinical physician for technologist.

> "The difference in motive (between the scientist and technologist) is reflected in the source of innovation. The direction of a scientist's work is likely to be determined by current fashions and this assures the required association with and stimulation from others on related problems. The broad goals of the technologist are usually set by the objectives of an organization rather than by fashions. We need both creative scientists who are broad enough to look beyond the current fashions and creative engineers who can appreciate scientific discoveries and incorporate them into technology" (25).

4. Barriers

Even in these times of instant remote communication and rapid worldwide travel, barriers of space and time between the source and potential users of innovations are important.

The economic factor is still an important barrier to acceptance of equipment innovations in the life sciences. In part, this is due to the inherent high cost of modern systems, and in part due to the tradition that the life scientist and clinician have worked with essentially simple tools, and do not mentally budget large funding for innovations.

The earlier description of the necessary characteristics of innovation and the communication process implicitly identified some barriers to innovation spread. In addition there are some forces of resistance which cannot be economically modified by the innovation disseminator. These forces - these unyielding barriers - must be considered in planning the introduction of a new idea as a new thing. These barriers are least strong in life science research (although there are important differences among the biological and behavioral sciences) and most deterring in clinical medicine.

In the practice of treating patients one detects a growing resistance to novelty for the sake of novelty, a conviction that the effectiveness and the side effects of any new device or material or procedure must be quite well understood to avoid the diseases of progress the iatrogenic threat to patient survival.

One such tragic result of progress was the by-product of superior engineering. The late nineteen-fourties and early fifties saw the development of blindness in nearly a third of all underweight premature babies born in the U. S. The blinding disease, retrolental fibroplasia, was traced to "excessive" oxygen being supplied to nursing incubators. Modification of air supply practice virtually eliminated this cause of blindness. An opthalmologist stated to us, half seriously, that the tragedy would never have occurred had not engineers perfected the leak-proof incubator which permitted virtually complete control of the atmosphere.

Thus in clinical medicine there is the barrier of time; innovation must be proven beneficial, and practical, in the research setting, and, frequently, in teaching hospitals, before the practicing specialist will adopt it.

An important consideration in the spread of innovations in medicine is the amount of new skill the acceptor must master in using the innovations. "Using" a new life science tool, implies not only operating it, but maintain and, most important, interpreting the meaning of the data yielded by the tool.

The great majority of practitioners in each life science discipline and medical specialty look to colleagues in their own field for innovations. The "not invented here" attitude of resistance to "outside" innovations is strong among those engaged in medical research and practice.

The increasing specialization of medical sciences brings with it increasingly more severe performance criteria for adoption of an innovation.

At the same time, the prospective disseminator and innovator in medicine cannot, typically, introduce statements of economic advantage of his innovations. The researcher and the clinician are generally not impressed with discussion of cost savings attributable to the innovations because the ultimate criteria of value to the investigator (advancement of knowledge) and the practicing physician (advancement of human health) are inherently immeasurable.

5. Stimuli

The term stimuli is meant to mean more than the absence of barriers. In the case of virtually every innovation acceptance there are forces operating which tend to facilitate use of the new ideas or things.

Economic stimuli, from the point of view of the medical field are not generalizable for the reasons cited earlier. While a hospital administrator will factor expected cost savings into his decision (or recommendation) regarding innovation budgeting, such a consideration is of marginal importance. Thus the economic model of innovation dissemination suggested by Mansfield* can be applied only loosely to the life science field.

Generally, the fewer the number of individuals who must be involved in the decision, the more rapid the differences.

Crisis, of course, accelerates acceptance of new ideas. Here is meant both the crisis of new opportunity (as in the field of genetics recently) and new problems (the growing numbers of the elderly).

Small steps are easier than big steps. An innovation that requires a relatively small commitment (of prestige, of risk to the patient or the experimental design, etc. as well as dollars will find a more ready response.

Competition is no less prevalent in the life sciences than any other human

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*to review: the probability of an individual, or an operating unit accepting an innovation $\approx$ (proportion of the "community" already using it, the expected profit, and some "progressiveness" descriptors of the community) divided by size of the investment.

activities, and, particularly in those fields which are advancing more rapidly, the competitive pressure is expressed in stimuli to try new tools, and embrace new hypotheses, rather than pressure to excell in marketing of established practices.

Availability of funding (whether from the government, in the case of research, or from lucrative practice in the case of certain of the medical specialties) is an important stimulus to try out the new.

6. Methods of Measurement and Analysis of the Process of Innovation Dissemination..

Investigators of the diffusion of innovations generally are interested in describing the process at least in terms of the time required to achieve an equilibrium level of adoption (i.e. the point at which the percentage of users is no longer growing). When the originator of the innovations is a commercial enterprise, he is in addition interested in measuring the cost of the introduction, relative to the profit its production returns. It can be expected that both the sociological student of the technological change process and the economist will in the future be able to measure and establish mathematical correlations among the factors which influence the acceptance of innovation. Thus, while we must now be satisfied with working with equalitative descriptions of individuals as "early adopters", or "laggards", etc. we can at least hope that in the future communities of prospective users can be described with some precision as objects of varying susceptibility to scientific and technological change.

The enormous samples of variables which interact in the flow of new ideas into and within communities defy detailed modeling without the use of computers. Computer simulation of community response to such innovations as fluoridation, presidential candidates, etc. now underway will contribute to the efficiency of OTU and others interested in predicting, planning and monitoring the dissemination of innovations. More specific action in these areas which might be adopted by OTU are included in the recommendations in Section V of this report.

Examples of Innovation Dissemination in the Life Sciences

The foregoing summary of the state of the art of the study of innovation introduction and spread drew from the work of observers of technological change in industry, agriculture and medicine. Before going to a discussion of just what NASA has in its inventory of science and technology to introduce and disseminate in the life sciences, a brief review of specific, recent cases of adoption of new space-related ideas seems appropriate. The cases were selected as representative of the kind of innovations which the life sciences can expect to receive from the space program, for they:

1) draw heavily from the physical sciences and engineering
2) entered medicine via medical research centers
3) represent an infusion and adaptation of new techniques into an existing area of medical interest.

The two cases are not representative in one significant respect: both are "spectacular", while we believe that the total impact of the space program, as will be discussed later, will be mainly constituted of a great number of "small" transfers of technology, and diffuse changes in attributes and modus operandi of research and clinical medical specialists. The first instance to be cited is proton beam surgery.

B. Proton Beam Surgery

This case exemplifies the role of mission oriented agencies (NASA and the military) in stimulating the refinement and dissemination of an innovation by providing a challenge closely related to a medical problem, and the funding to address it. The space-originated challenge was to determine the hazard of cosmic radiation to space travelers. The medical problem was to explore the potential value of high energy particulate radiation as a means of carefully controlled tissue destruction.

During the past 35 years astrophysicists have been increasingly interested in investigations concerning the physical nature and origin of the enormously energetic cosmic particles which bombard the earth. Initially, studies of cosmic particles were directed toward gaining further insight into the nature of energy and matter. However, with the advent of the space age and the probability that man would actively participate in space exploration, emphasis was placed on the study of the biological effects of high energy particulate radiation.

Prior to May of 1958, it was assumed that the radiation level due to cosmic rays and electromagnetic radiation would be sufficiently small as to not constitute a serious hazard during space travel. Early rocket data confirmed that the radiation hazard was small, but in May of 1958, the assessments of the hazard were dramatically changed with the announcement by Dr. James Van Allen, of the discovery of belts of heavy particle radiation, and subsequently of intense proton irradiation during solar flare activity. It was essential to obtain information regarding the relative biologic effectiveness of the highly energetic protons and other cosmic nucleons, some with energies over a billion electron volts, prior to undertaking prolonged manned space voyages. These findings brought a bout increased research effort into the radiobiology of high energy particles, which in turn led to new and significant innovations in medical radiation treatment.

For the past three decades there have been many efforts in experimental radiation therapy to produce therapeutically effective ionization in deep lying diseased tissues without producing excessive damage to superficial healthy tissues. Despite the use of more energetic radiations, such as Cobalt 60 gamma rays and supervoltage x-rays, and the utilization of "cross-fire" techniques, the damage to healthy surrounding tissues still inhibited effective depth irradiation therapy from existing external radiation sources.
In 1946, Wilson (26) suggested that fast protons might be used in radiation therapy for the selective destruction of deep tissues. The rationale for this suggestion was apparent from the linear energy transfer characteristics of such high energy accelerator produced particles. The linear energy transfer for fast protons sharply increases toward the end of the proton track as it penetrates a material. The location of this sharp peak, the Bragg Peak, with heavy ionization density in relation to the shank of the beam depends on the

proton energy and the material being irradiated. Consequently, it would be possible to selectively irradiate deep tissues while at the same time exposing the more superficial tissues to significantly smaller amounts of radiation. Furthermore, since the protons only penetrate to a given depth, the far side of the irradiated locus would not receive any radiation (unlike the conventional x-ray or gamma ray therapy). In 1952, the first study on the physical properties of high energy nucleons and their biological uses were reported (27). This work was performed at the Donner Laboratories in Berkeley and was made possible with the completion of their 184 inch cyclotron. Subsequently some promising preliminary studies reinforced the need for the development of this new biomedical tool. A number of these early studies are briefly described in the following section.

Non-Surgical Destruction of the Pituitary

Destruction of the pituitary has been shown to be effective therapy for the following:

a. the treatment of acromegaly, an abnormal proliferation of certain cells of the anterior pituitary.

b. hypophysectomy to inhibit malignant tumors of endocrine and reproductive tissues.

c. hypophysectomy for advanced cases of diabetes mellitus complicated by retiropathy and other vascular degenerative changes.

d. malignant exophthalmos.

Due to the location of the pituitary, conventional radiation treatment is undesirable due to the possibility of severe damage to the nearby cranial nerves. Surgical extirpation is effective but since it involves a certain amount of risk to the patient it seemed that high energy heavy particle irradiation might be the therapy of choice. The first use of high energy (340 Mev) protons on humans was reported by Tobias and his group in 1958 (28). The pituitary was successfully irradiated, but there were many severe side effects due to damage to the surrounding brain and cranial nerves. It became apparent that not only dose and dose rate were important but also the volume of tissue irradiated influenced the degree of damage. In order to further reduce damage to surrounding tissues, multiportal rotation techniques were adopted. Doses ranging from 14,000 to 30,000 rads were given to 26 patients with advanced metastatic mammary carcinomas and although the majority of these patients died (most were already in terminal condition), two showed marked improvement and survived almost two years. This finding was sufficient to suggest that further work on non-terminal patients would be beneficial and 150 additional cases were treated (27.) In these patients almost half showed regressions of the tumors for considerable periods of time. Recent work on high energy nucleon irradiation of the hypophysis with 900 Mev alpha particles on 17 cases of acromegaly and chromophobic adenoma has been reported by Lawrence and Tobias and their group (29, 30, 31, 32). Their results showed that doses of 4000 to 7200 rads produced an effective and relatively safe treatment which halted growth in acromegalies without completely destroying the pituitary.

Other recent work reported at the Massachusetts General Hospital (MGH) Proton Beam Seminar Series includes the studies at the Harvard cyclotron by the Neurosurgery Department of MGH. This work has yielded promising results on a number of advanced diabetic patients with marked retinopathy and other vascular degenerative changes. In the 17 patients done to date, the majority have shown marked improvement following high energy proton irradiation of the pituitary. Relatively few have shown cranial nerve damage and the insulin requirements have dropped considerably. Large scale studies are now possible due to a grant by NASA which began in January, 1962, providing both considerable time on the cyclotron and facilities at the site for biomedical studies (33).

High Energy Particle Irradiation of the Brain and Other Tissues.

It quickly became obvious that focal destruction of brain tissue by high energy nucleons could be of considerable value in both clinical applied techniques and in basic studies on the physiology of the central nervous system. Of immediate interest is the possibility of high energy particle irradiation for the following purposes:

a. the treatment of malignancies located deep in the brain mass.

b. selective placement of lesions to treat Parkinsonian symptology (34, 35)

c. treatment of symptoms of cerebral palsy.

d. possible localized placement of lesions for psychosurgery, short of the medical surgical procedures of prefrontal lobotomy done by Freeman and Watts.

e. treatment of deep carcinomas in relatively inoperable loci outside of the brain.

The first proton irradiation pilot studies on human patients with brain tumors have been completed on human patients by Kjellberg at Massachusetts General Hospital (33). In cases completed so far, transient improvement of symptoms was noted in almost all patients. (One of the major problems to date has been the accurate localization of the tumor's outer boundaries). Another pilot study of seven cases of human carcinoma irradiated with a beam of high energy protons has been reported by Falmer, et al in Sweden (35). Even in cases in which the entire pelvis was irradiated a single proton dose of 3000 rad produced obvious regressive changes without producing severe damage to skin or urinary tract.

A group at Upsala (36-41) reported heavy particle surgery as early as 1959. Localized lesions in the central nervous system of the rabbit produced by a 185 Mev proton beam were reported at that time. The zone of destruction was sharply delineated to correspond with the path of the beam and only minimal hemorrhages were seen. Areas of necrosis could be observed in the cord and these degenerative changes were attributed primarily to vascular damage rather than to selective effects on neurons. In another study 4 pigeons were decerebrated with radiolesions produced by 155 Mev protons. It is significant that much of this Swedish work was sponsored by grants or contracts from the U. S. Air Force and was prompted by concern over the space radiation problem. The Swedish investigators visualized the uses of irradiation in bloodless localized human neurosurgery from the start of their early studies. The first successful treatment of a small group of patients with psychic disorders and Parkinson's disease was reported by Leksell at the International Congress of Neurosurgery in 1961 at which members of other groups using cyclotron produced high energy nucleons were in attendance and also presented papers.

Animal studies at the Donner and the Lawrence Radiation Laboratories (42-46) have provided considerable data which could not have been obtained through human exposures. However, a human pituitary treatment as early as 1959 was reported in a recent review by Linfoot, et al. (47).

At the Harvard cyclotron several studies of similar nature to the Donner and Lawrence Laboratory animal work are now in progress. Two such studies are investigating the interrelation of proton beam irradiation with radiation potentiating compounds. In the past, such studies using x-rays were not very promising due to the fact that healthy surrounding tissue also took up the potentiating compound and greater damage to normal tissue would result.

However, with the use of the Bragg peak of high energy nucleon beams, it is now possible to get high doses of irradiation localized at a given site and thus might permit the use of chemical potentiators to develop a more efficacious therapy.

In some yet unpublished findings by Kjellberg at MGH, Levy at Boston University, and Sondhaus at Berkeley (48) it appears that the biologic effects of a given total dose increase markedly as the dose-rate is increased. If these observations are confirmed it would mean that since the Bragg peak dose-rate is greater than the beam shank dose rate the relative biological effects would also be greater. This would further enhance the capabilities of this method.for differential tissue destruction by bloodless surgery.

The initial research effort to determine the hazard of high energy particulate radiation to the space traveller has shown that under most circumstances (discounting prolonged flight in the Van Allen belts) the probability of damage to the astronaut is indeed negligible (49-57). This being particularly true in light of the classic study of Zeman, et al. (58) on the histopathologic effect of high energy-particle microbeams. Using small beams (still greater than the dimensions of a clustered particle) it was found that extremely high doses (400 kilorads) were needed to produce a microlesion. Thus it seems unlikely that single hits would produce either functional or organic disruption of biologic function. On the other hand the fruits of this research have found new practical application in radiation therapy and nerosurgery which are extremely promising and application of these high energy particles to basic studies in biology, biophysics, and radiation biochemistry have also provided some valuable insights. Recent research interest has increased considerably and it is expected that even greater effort will be applied in the future. The primary limitation to date has been the small amount of time available on the high energy accelerators. This has in part been alleviated by NASA, AEC, and Air Force grants, but the need for new particle irradiation facilities for biomedical applications is still the critical limiting factor. Tobias' group at Berkeley has received research grants from NASA totaling about one and a half million dollars since 1961. Grants from NASA to the Harvard group have amounted to about a half a million dollars.

The development of the biomedical uses of accelerator-produced high energy particles has been marked by frequent exchanges of information among those presently active in this field. Special symposia have been important in this respect. For example, at the 32nd annual meeting of the Aerospace Medical Association, April 1961, in Chicago a number of papers summarizing and presenting new data on effects of high energy particulate radiations were presented in a special symposium on Aerospace radiobiology. At the Second International Congress of Neurological Surgery, held in Washington, D. C. in October of 1961, all of the principle groups doing high energy work presented a review of methods and findings. The First International Symposium on the Effects of Ionizing Radiations on the Nervous System, sponsored by the International Atomic Energy Agency, was held in Vienna in 1962 and included papers by Tobias and his collaborators from Berkeley, and Zeman from Brookhaven on the effects of high energy particulate irradiations. In addition, four papers were presented on the effects of high energy particle irradiations at the Second International Symposium on the Response of the Nervous System to Ionizing Radiation, held in August of 1963 at UCLA under the joint sponsorship of the U. S. AEC and the National Institutes of Health.

The role of personal communications as a channel for the dissemination of information and ideas has been particularly important in the development of biomedical applications of high-energy particles. Dr. Kjellberg of the Massachusetts General Hospital (MGH) visited Dr. Tobias' laboratory at Berkeley in early 1960 to learn the techniques already in use. In May of 1961 the first of Kjellberg's patients was irradiated at Harvard. Exchange was furthered when Dr. Wang who had worked with Tobias came to the MGH. Within the Boston life science community there were frequent interchanges of information, some of which resulted in a return of new information to Tobias' group. For example, Dr. C. K. Le y, a radiobiologist at Boston

University with an interest in neurophysiology, met Kjellberg through a mutual friend and arranged to use the Harvard accelerator for certain plant studies. Subsequently Levy was invited by Tobias to give a seminar at Berkeley on the effect of high energy charged particles on the sensitive plant Mimosa Pudica. The personal communications channel is not restricted by national boundaries and is especially important when new laboratories are being established. For example, an English physician recently spent a year working with Kjellberg learning techniques which would be of assistance in setting up a similar program in England.

A large number of technical publications have appeared as evidenced by the bibiliography. In addition to those cited a number of other related articles have appeared in a diverse group of publications reaching a wide range of disciplines. Some of these articles, the journals in which they appeared, and the audience reached are indicated below.

Title	Journal	Principle Discipline of Readers
Accelerators in Biology and Medicine	Nuclear Instms and Methods 6:96-100, 1960	Physicists
Production of Laminar Lesions in Cerebral Cortex by Heavy Ionizing Particles	Science 126:302, 1957	Broad Audience of Scientists of Disciplines

Effects of Heavy Ionizing Monenergetic Particles on the Cerebral Cortex	J. Comp. Neurol. 115:219-242, 1960	Neurologists Neurophysiologists
Heavy-particle Irradiation in Neoplastic and Neurologic Disease	J. Neurosurgery 19:717-22, 1962	Neurosurgeons
Protection of Proton-Irradiated mice after PAPP and MEA	Radiation Research 19:229, 1963	Radiobiologists
Alpha particle and proton beams in therapy	Am. J. Med. Sci. 246:479-84, 1963	Broad Medical Sciences, all disciplines
Medical Research with High Energy Heavy Particles	Nucleonics 21:56-61, 1963	Engineers, health Physicists, Physicists
Effects of Heavy High Energy Charged Particles (4 papers)	Arch. Pathology 76:497-526, 1963	Pathologists
The Deuteron Microbeams as a Tool in Botanical Research	Radiation Botany 1:255-268, 1962	Botanists

A number of review sources are also available which have been useful in communicating information concerning the biomedical uses of high energy particulate radiation.

Periodic press releases and even television coverage have been used to publicize advances in high energy particulate work. For example, at the formal opening of the new Cyclotron Building at Harvard, good press and television coverage was provided. Publicity has been good, as evidenced by the large number of patients referred to Kjellberg's group by other Boston hospitals, and even by the NIH in Bethesda.

It is interesting and not at all surprising that the Soviet's interest and development of high energy accelerators has paralleled our own. Although their progress in the study of radiobiology of high energy particles is not completely known, the available reports suggest that they are undertaking an extensive program. As in our own program, the initial reports dealt with problems of biology in cosmic flight (55, 56), and subsequently resulted in laboratory studies on the relative biologic effectiveness of accelerator produced high energy radiations (59-60). In 1960, a review was published in a Soviet journal on the application of high energy radiation for the bloodless destruction of brain tissue (61). It is probable that Soviet work paralleling our own is continuing in this area.

C. Biomedical Applications of Lasers

Our second case was selected to present what amounts to a classic example of a new technology entering medicine from physics and rapidly disseminating throughout the life sciences. The following discussions will present the innovation and communication phenomena which accompanied this dissemination.

The OPTICAL MASER, or LASER (Light Amplification by Stimulation of Emitted Radiation) is selected because it represents, in concept and performance, a departure from any previously known device; it is of recent discovery, so that its first appearance can be pin-pointed in time and the first biomedical application followed so soon upon the laser's discovery that the skein of the informational thread can still be followed with relative ease.

Citation of the laser as a case of interdisciplinary diffusion of innovation understates the general dissemination problem because the tremendous importance of the discovery assured it greater publicity than would be given to a less spectacular development. In a sense, this aspect of the analysis strengthens the conclusions to be drawn: whatever steps were operative in disseminating laser-information must be greatly multiplied or intensified if it is desired to disseminate less publicity-prone discoveries.

Physical theory and engineering specifications are not germane here. Biologically, it is important that the laser emits a beam of light of unprecedented spectral purity and homogeneity, focussable onto a small area with unprecedented intensity.

Analysis of this "success story" indicates the existence of many conditions which favored the spread of the laser within medicine. Among them were:

Characteristics of the innovations

1. essentially simple

2. inexpensive, and not requiring elaborate supporting equipment.

3. analogous to other tools which have been used in medicine (photocoagulator used by opthamologists, for some time. UV and IR sources used by dermatologists, etc.)

4. inherently significant

5. its use was prestigious.

Communications

1. sheer volume of publications (and publicity) accompanying it.

2. occurence of publication, and organization of symposia of an interdisciplinary nature.

3. rapid conversion of theory to hardware, and the inherent simplicity of the laser encouraged development of a laser manufacturing industry, whose marketing staff was quick to promote biomedical application.

Acceptance of the innovation

1. as cited earlier, physicians accustomed to using optic technology were early adopters.

2. typically, acceptance of the laser involved a close working relation between a physicist and a biomedical specialist.

The theory of the laser was published in December, 1958, by physicists working at Columbia University and at the Bell Telephone Laboratories. The first hardware-functioning lasers had been developed by 1960.

A few months later (October, 1960) a physicist concerned with laser development realized that the device might be of use to ophthalmologists practicing retinal photocoagulation. After a succession of refusals, he did succeed in interesting a researcher at New York University, who began preliminary experiments. In all, and excluding much classified work, 23 publications concerning lasers appeared in 1960, not one of them biomedical.

In 1961, lasers came into the general news, when scientists suggested that they might be used for interstellar and intergalactic communication.

This idea greatly helped to publicize lasers.

Subsequently, during the same year, the first biomedical application - retinal photocoagulation - was published, and technical publications increased to more than ninety.

During 1962, an estimated 400 laboratories became engaged in (non-biomedical) laser research, the Federal government spent an estimated $20,000,000 on research and development, and scientists at the Massachusetts Institute of Technology had succeeded in illuminating a 2 miles square patch of moon-scape.

In the biomedical areas, 1962 saw several papers suggesting a variety of possible applications, and a continuation of the original (photocoagulation) work.

By 1963, non-secret military research and development projects numbered 128. In April of that year a Symposium on optical masers was convened for three days at the Brooklyn Polytechnic Institute. A single biomedical paper was read; it dealt with laser-induced electrolytic changes in blood and plasma, and suggested applications in neuro-surgery. Other researchers during the year published on the effects of lasers on skin, cancers, tissue-cultures, single cells and cellular organelles. In all, some 20 institutions were conducting biomedical research on lasers, and manufacturers reported the sale of some 40 laser-coagulation units.

Bibliographic Analysis

Laser theory was first described in Physical Reviews, a journal that probably has little readership among biologists or physicians. The announcement of the first working model, however, appeared in Nature, an interdisciplinary British journal with wide distribution in the U.S. Nevertheless, it is doubtful that this article evoked much "resonance" among biologists, or that it stimulated biologic "metaphorical thinking." Possibly more stimulating to a biomedically oriented intelligence may have been the (terminal) paragraphs of an article in Scientific American, ("Optical Masers") of June 1961, in which the physicist A. L. Schawlow discussed the possibility of using laser-radiation to excite specific molecules in a molecular mixture (in which the other molecules would remain unaffected). Though the author does not mention the biological implications of this laser-effect, these would be immediately apparent to any biologist.

The first bona fide biomedical use of the laser - retinal "welding" or photocoagulation - appeared in November 1961, in Science, an interdisciplinary publication with wide distribution among all life science disciplines. Shortly thereafter, (January, 1962) an article on laser technology and applications also appeared in Science, but contained little of biomedical interest.

An article, suggesting a wide variety of possible biologic applications for lasers appeared in March, 1962, in the Biophysical Journal, a fairly recent publication that probably is read fairly widely, at least in the larger (or more active) biomedical research centers. In this article, a physicist discussed the following possibilities for lasers: intense illumination for microscopy and for the high speed photomicrographic recording of rapidly moving objects (e.g. flagellae); microsurgical effects, and directed and limited damage to cellular structures by laser's thermal and/or ionizing effects (e.g. "heating a particular part of a chromosome", or of a "very short section of nerve or muscle fiber".); dermatologic and ocular surgery; ultra-high-resolution spectroscopy (under certain conditions) of subcellular structures; more effective interference microscopy (which would suggest to a biologist also more effective phase-contrast and polarizing microscopy). In May, the Industrial Hygiene Review - biomedical publication with a somewhat limited readership - published an article discussing the safety aspects of laser technology.

In December, 1962, some possible biomedical applications of lasers are suggested in one paragraph of a general paper on lasers in the Journal of the Franklin Institute of Philadelphia, a serial with some readership among biomedical engineers and biophysicists

Laser-induced skin lesions were described in January, 1963 in Life Sciences, volume I, number 1, a brand-new publication that may have been read more widely than similar journals just because of its newness.

At the same time a second paper on retinal applications appeared in the *Archives of Ophthalmology*, clearly a "sectarian" publication. Two more publications concerning the dermatologic effects of lasers appeared in March of the same year, one in a highly specialized biomedical publication (*J. Investigative Dermatology*), the other in the interdisciplinary *Nature*.

In July, 1963, newspapers carried an article describing preliminary experiments on cancers. Nearly simultaneously, there was another article - primarily physical - on lasers in *Scientific American*.

A brief paragraph concerning laser energy appeared in August, 1963, in the *Medical Research Newsletter* of the Pasadena Foundation for Medical Research, and at about the same time a specialty organization (Sawyer Foundation) began amassing a laser-bibliography for the Stanford Medical School. Finally, In October, there was a widely heralded talk on the cancer experiments given at the annual convention of the American College of Surgeons, which reached the public press.

The translation of physical and engineering developments into biomedically useful information requires a certain amount of "metaphorical" thinking among both the biomedically and the non-biomedically trained, each in the other's discipline. It also requires propinquity among these men of different backgrounds. In this connection, it is interesting to note that the author who first drew attention to many of the biomedical implications of lasers is a physicist, but that in his article he acknowledges the help his "metaphorical thinking" received from three well-known biologists, working at the same university.

In general, interaction of disciplines may be most effective in a University environment as is clearly illustrated also by the following quotation from a letter written by William A. Baker, a physicist and a consultant (on Lasers) to the McDonnell Aircraft Corporation: "At St. Louis University, where I teach Physics, Dr. Privitera and I have been planning to study the effects of low-power laser radiation ... on amoebae and other primitive life forms."

The first suggestion for using lasers in retinal photocoagulation was made to the investigating ophthalmologist by a physicist, working for a firm involved with the manufacture of lasers. The physicist knew (his uncle is an ophthalmologist!) about photocoagulation techniques and, in a typical example of "metaphorical thinking", contacted a number of ophthalmologists. Similarly, it seems natural that dermatologists should have been involved early, as they, too, use (UV, IR) radiation frequently. Furthermore, manufacturers of such a powerful, radiating device as laser, might well be expected to concern themselves with the device's biologic and dermatologic effects because of in-plant and general safety considerations.

Finally, it may be of interest to note that, among the twenty teams currently investigating biomedical laser effects, all are either conducted by biologists with the assistance of laser technologists (physicists) from the laser producing firms, or are undertaken at these firms directly.

IV. COMMUNICATION OF GOVERNMENT RESEARCH

A. Introduction

"Transfer of information is an inseparable part of research and development. All those concerned with research and development - individual scientists and engineers, industrial and academic research establishments, technical societies, government agencies - must accept responsibility for the transfer of information in the same degree and spirit that they accept responsibility for research and development itself."

With this charge, the President's Science Advisory Committee (4) proceeded to develop its recommendations to the technical community for improvements in the transfer of information. Although a large portion of responsibility for information transfer must ultimately reside with the individual scientist, the communications framework within which he operates, the inducements and impediments to communication, will influence the spirit and effectiveness of his response. Government agencies can and should provide the framework and inducements for better communication of research results. Unfortunately there are many uncertainties regarding how to improve the transfer of information and therefore the steps which government agencies should take to most effectively disseminate information, particularly biomedical information, are poorly defined. Research is underway to attempt to elucidate these factors, but only on a relatively small scale. Senator Hubert H. Humphrey, Chairman of the Subcommittee on Reorganization and International Organizations, Committee on Government Opera- on, U. S. Senate, in March of 1962, reported that although steps have been taken by the U. S. Public Health Service "its information policy, organization and procedures are hopelessly out-of-date and inadequate" (62). Senator Humphrey went on to observe that the National Institutes of Health were at that time spending only a fraction of one percent of their research funds to finance research on how best to disseminate research findings. It is implied that the need for further information on dissemination procedures is self-evident and that Congress is sympathetic to the needs for financing research in this area.

The objectives of Federal agency programs in information transfer are to report and disseminate the results of research, new ideas, and innovations as widely and as rapidly as possible. However, with respect to innovations, the dissemination of information does not insure adoption.

It is axiomatic in the innovation diffusion process that an individual adopt a new idea as a result of his being "told of it" in the right place, at the right time and in the right way. It is incumbent upon the government - the largest sponsor of innovations - to insure that <u>all</u> potential users of its ideas

1) are aware that the ideas exist

2) know how to get a description of them

3) are aided in retrieving the desired information.

Ideally NASA would foster the use by life scientists of the ideas it has sponsored by:

1) making all of its life science research quickly, easily and constantly available to all life scientists.

2) informing life scientists * of the kind of information it has in the physical sciences and engineering, and insofar as possible, announcing such information in terms meaningful to probable users in the life sciences.

3) strongly encouraging the scientists it supports to get their ideas out into the community.

The following sections of this report review how NASA is currently going about doing this, and how its procedures compare in nature with those used by another mission-oriented agency (AEC) and a basic research-oriented agency (ONR). The National Science Foundation has been most active in the study of the problems of communicating the results of government-sponsored (and other) research. One of its contributions to the scientific community has been to publish, in a standard format, the information services of various federal agencies. As of October, 1963, papers had been published by the Foundation describing the information services of the following agencies: Departments of Agriculture, Commerce, Interior, Treasury, and Air Force, the FAA, Government Printing Office, Office of Naval Research, TVA, Veterans' Administration, FCC, the Smithsonian Institution, and NSF itself.

*and those who support the life scientist: bio-mathematicians, etc., and the medical equipment and material industry.

B. National Aeronautics and Space Administration

The policies and procedures which NASA uses to disseminate its research results and to disseminate other information of significance to NASA programs are outlined in the following paragraphs. At this time NASA does not have a published set of official policies and procedures defining the information gathering and dissemination program, but such a manual is in preparation.

The current NASA information transfer program is operated according to the following principles (63):

a. Documents should be written for, and dissemination directed to the ultimate consumer of the information - the scientist, the engineer, and the laboratory worker.

b. The value of information may depend on the timeliness of its transfer. Therefore acquisition, processing, and dissemination must proceed without delay once an item of information is discovered.

c. Integration of the NASA information transfer program with other programs will enhance the effectiveness of each system. The NASA Office of Scientific and Technical Information (OSTI) works closely with the Armed Services Technical Information Agency (ASTIA), AEC Division of Technical Information, National Science Foundation, Department of Health, Education and Welfare, Office of Technical Services (OTS) in the Department of Commerce, Federal Aviation Agency, and a number of professional societies to insure prompt exchange of information.

d. Decentralization of storage and secondary dissemination sources provide more rapid access to the information by more users. NASA automatically distributes documents to the OTS depository libraries and to universities, colleges, public libraries, and domestic organizations which agree either to exchange information with NASA or to maintain depositories of NASA publications for public use.

e. Technical reports which are the primary records of NASA research must be supplemented by secondary publications which review, collate, resynthesize, and integrate the mass of material in the primary records.

NASA formal reports are prepared as the basic information source which describe as fully as possible important NASA research results. Responsibility for preparation of these formal reports lies with the individual Research Center and the Program Office. These reports are reviewed at several levels before release to OSTI for printing and dissemination. NASA Technical Notes are published to cover studies of more limited scope. Reports which will have limited distribution, for security or other reasons, are published as NASA Technical Memoranda. NASA also publishes a series of Technical Translations covering information published in foreign languages which are judged useful to NASA projects. A series of NASA contractor reports and a series of reprints of published articles (reporting NASA sponsored research results in scientific and professional journals) are planned. In the past only a selected few contractor reports have been published as NASA formal reports.

NASA is also producing a number of Special Publications which include proceedings of certain conferences of symposia, state-of-the-art monographs, handbooks, and special purpose reports. In general, these special publications are prepared by organizations or individuals outside OSTI.

Formal NASA technical publications and abstract journals are automatically distributed to NASA centers, contractors, sub-contractors and grantees, other government agencies and their contractors, depository libraries at most universities, a large number of public libraries, the 12 Federal Regional Depository Libraries, and to other organizations which agreed to exchange technical information with NASA or to maintain depositories of NASA publications for public reference. Unclassified formal NASA publications are also released to OTS for sale to the public.

Questionnaires proposed by the project staff were sent to twelve depository libraries in early 1963 in an attempt to assess what groups might be using NASA disseminated information. Eight libraries returned completed questionnaires. Responses to questions are listed below.

1. Seven libraries did not announce newly received NASA documents. One library circulated a monthly list of government publications received.

2. Seven libraries reported that newly-arrived NASA reports were not distributed to research or other groups for review. The other library responded that although not automatically distributed for review, all NASA documents were filed in the aeronautical section where they were heavily circulated among faculty, research groups and students.
3. Five libraries reported that NASA documents were used primarily by aeronautical engineers, one cited applied mathematics, and two libraries reported that they could not estimate which disciplines made the most use of NASA documents. Industrial firms and mechanical engineers were mentioned after aeronautical engineers, as secondary groups in frequency of use of NASA reports.
4. Only four of the libraries could report that they had received requests for NASA documents from medical or biological research groups.

The Director of OSTI recently summarized the duties of his organization with the statement, "Our job is to provide effective communication". Thus affirming that the collection of information and the making of this collection available to those who want it is not sufficient to promote the effectiveness of NASA literature. NASA has contracted with the Library of Congress to abstract the world aerospace medicine literature. These abstracts have been published in the Journal of Aerospace Medicine. NASA has also contracted the American Institute of Aeronautics and Astronautics to provide an abstracting and announcement journal covering aerospace publications in both foreign and domestic journals. Abstracts from the Library of Congress group are now included in this publication, International Aerospace Abstracts (IAA). Documentary and technical report literature, both domestic and foreign whether generated from NASA's own program or not, are abstracted and announced in the semi-monthly Scientific and Technical Aerospace Reports (STAR). Together IAA and STAR provide comprehensive reference service covering the aerospace field.

With respect to transfer of information by NASA grantees or contractors, no official policy has been published. Reporting requirements are established for individual contracts or grants, but official procedures and policies governing publication in the scientific literature or presentation at technical meetings are not available. Since many contractor reports are not widely disseminated, and since the results may not be summarized in formal NASA reports until considerable time has elapsed, a system for reporting new technology has been established. Contractors are required to continually review the results of the work performed to identify innovations ("A means of accomplishing a work objective either more effectively than before, or for the first time"). Reportable items are to be promptly reported in writing, and every six months a summary of the review activities is to be forwarded to the Contracting Office, regardless of whether or not reportable items have been identified. After completion of the contract work the contractor must list all reportable items or certify that there were no such items.

C. U. S. Atomic Energy Commission (AEC)

The AEC maintains a Division of Technical Information (DTI) which is responsible for the development of technical information policy, and which performs certain specialized information dissemination functions. In general, the preparation and distribution of most technical reports is carried out or a decentralized basis by AEC contractors. However, DTI continuously reviews the foreign and domestic literature in the field of atomic energy, announces sources of information, and abstracts and indexes such information. In addition, DTI prepares bibliographies; both comprehensive formal bibliographies, and less formal "literature search" bibliographies. AEC technical information services are described in detail in TID-485 (4th rev) available from DTI Extension in Oak Ridge.

AEC sponsored research results are disseminated through a) Technical Reports, b) Technical Books, Reviews, and Conferences, c) Publication in the open Scientific literature, and d) Abstracts and Bibliographies. The technical reports issued by the AEC or its contractors may be: a) topical or final reports, b) progress reports, or c) nuclear explosion effects reports. The topical or final reports "contain accounts of completed investigations on a specific subject." Progress reports "summarize the results of work on particular projects at periodic intervals". (64) The nuclear explosion effects reports are of a special nature and need not be considered further in this discussion. The policy governing the generation of these reports is:

> All research and development activities productive of significant information shall be promptly and fully reported to the AEC.
>
> Technical information resulting from research and development work shall be reported in distributable documents for dissemination as the AEC directs. (64)

Technical reports are distributed by the issuing organizations to installations having an interest in, or a requirement for, the information in the reports. DTI Extension in Oak Ridge receives sufficient copies of the reports to fill specific requests and for distribution to other organizations which have a need for the information but are not listed in the standard distribution list. Standard distribution lists are prepared periodically by DTI and lists organizations which will automatically receive reports in selected subject categories. The issuing organization also indicates to DTI Extension if the report would be pertinent to the work of other installations listed in the standard distribution list under a different category. Copies of unclassified AEC Technical Reports are supplied to depository college, university and public libraries as well as other government agencies and contractors. Depository libraries outside the United States and official foreign agencies may also receive these reports. In addition to abstract journals for classified reports the AEC provides the semi-monthly Nuclear Sciences Abstracts and every three months the Research and Development Abstracts of the AEC. Information from a wide variety of sources are indexed and abstracted in these journals.

The AEC contracts for preparation of Technical Progress Reviews which "digest and evaluate significant developments in selected areas of nuclear science and technology". These reviews also serve as summary and reference sources for the dissemination of information gained in both the classified and unclassified programs. Reviews are issued quarterly in each of five specific technical areas. Dissemination of these reviews is automatic to official users and may be obtained by others on an individual-issue or annual-subscription basis from the Superintendent of Documents, U. S. Government Printing Office.

"The AEC and its contractors sponsor, support, or participate in virtually all important meetings and conferences on atomic energy" (64) Proceedings of these meetings sponsored by AEC, or in some cases even when not sponsored by AEC, are published and issued as Technical Reports. DTI arranges for the translation and distribution of foreign language books and proceedings, and AEC contractors generally procure translations of shorter works relevant to specific AEC projects in individual laboratories.

The AEC actively encourages publication by contractor and AEC personnel of unclassified work in established scientific and technical journals. In addition, AEC contractors may exchange information with other individuals or organizations

"It is the policy of the AEC to permit and encourage, to the maximum extent practicable, the dissemination and exchange of unclassified technical information among scientists and technicians of this and other nations. The purpose is to provide that free interchange of ideas and criticism which is essential to peaceful scientific and industrial progress of mankind and to enlarge the fund of technical information."(64)

Copies of Exchange material received by contractors should be sent to DTI Extension for possible referencing and abstracting. Copies of papers submitted by AEC contractors to technical journals or intended for presentation at technical meetings should also be sent to DTI Extension for general dissemination, referencing, and abstracting. In general, all reports which do not appear as journal publications or oral reports (to be published in proceedings) are given standard distribution, this includes internal or informal reports by the contractor. The originating organization must justify any recommendations for distribution limitations.

D. Office of Naval Research

"Full disclosure of information obtained under research programs supported by ONR is a requirement in all contracts. It is the responsibility of every Scientific Officer to ensure that these reports are made available to those who need the information and have the proper security clearance." (65)

Reports from ONR supported investigators are intended primarily to keep ONR advised concerning progress and results of the research project. In addition, project reports may be used to communicate information to other scientists who need such information more rapidly and in great detail than might take place through conventional scientific communication channels. However, "the general policy of ONR is for the interchange of scientific information to take place in established channels. Furthermore, it is the policy of ONR to strengthen these channels when desirable." "Since payments under ONR contracts are contingent upon compliance with the report requirements, timely submission of reports is advised." (65) There is moderate flexibility in the type and frequency of reports required, thus allowing the ONR Scientific Officer to tailor report requirements to the individual contract need.

Contractors prepare technical reports when specific phases of the project are completed or when research results of sufficient importance to justify wide dissemination are obtained. These reports are not issued at fixed intervals, "but each is expected to be scientifically complete". ONR will accept reprints of published articles as technical reports if they meet the above criteria. An annual summary report is required if no technical report is issued during a contract year. At the completion of each contract task a final report will be issued summarizing all work accomplished and referencing technical reports for any details previously reported. The final report also includes an index of all technical reports and publications issued under the contract.

For each report the investigator follows an "authorized distribution list" which may not be changed without the approval of the Scientific Officer However, the Scientific Officer has the freedom to make up a special distribution list for a report when he feels it is advisable. It is the responsibility of the investigator to make the initial distribution of his reports. In practice, manuscripts which may ultimately be designated as unclassified technical reports may be distributed to anyone in the scientific community that the investigator feels should receive such information. This dissemination, prior to approval of the technical report, is considered to be advanced information and not an official report.

The Defense Documentation Center is always included in the authorized distribution list. Immediately upon receiving the report DDC distributes the report through ASTIA to DoD agencies. Unclassified reports cataloged and abstracted in the ASTIA Technical Abstracts Bulletin (TAB) are released to OTS for announcement in "U. S. Government Research Reports" and sale to the public.

Additional information dissemination is encouraged in several ways. When a research program is first initiated, a work statement of the research to be performed is transmitted by ONR to the Scientific Information Exchange. In addition, "it is the policy of ONR to encourage scientists working under ONR contracts to present the results of their investigations at scientific meetings" (65.) No prior approval is necessary for expenditure of contract funds to cover expenses for attending domestic scientific meetings at which subjects relating to the research contract are presented. In general, each investigator has in his contract funds provisions for attending at least regional society meetings in his specialty. Travel to meetings outside the U. S. is permitted on contract funds, but prior ONR approval is required for such expenses. Presentation of papers at domestic meetings does not require prior approval, although copies of the abstract of the talk should be forwarded to the Scientific Officer and Contract Administrator. ONR supported investigators are encouraged to publish in the scientific literature. Established page charges assessed by scientific or technical journals are an allowable contract cost. No prior approval for unclassified publications are required, but "at the time an unclassified manuscript is sent to the editor, the author should forward a copy to the cognizant Scientific Officer for information and review." However, security and policy review is required before submission of a manuscript to a foreign journal

E. Inter-Agency Comparisons

In regards to contractor or grantee activities, leading to the publication of government sponsored research results in the scientific literature, presentation at scientific meetings, or exchange between scientists or organizations, both ONR and AEC have a positive policy of encouragement while NASA has no published policy. With respect to technical reports, both AEC and ONR require contractors to submit their research results in a form suitable for distribution as a technical report. Primary dissemination of such reports is made by the contractor. However, under NASA procedures only a limited number of contractor reports are released as technical reports, and then often only after a modest delay for review.

In general, scientists are highly motivated to have their work published in scientific journals. Although number of publications is not a reliable index of scientific accomplishment or competence, it is commonly used for such purposes. It is therefore anticipated that much of the NASA supported research which is not now appearing in print will eventually be submitted for publication.

A survey was undertaken to determine the comparative numbers of recently published articles in selected life science or interdisciplinary journals which describe results of NASA or military service sponsored research. Journals reviewed were the Journal of Applied Physiology, Journal of Neurophysiology, Journal of Physiology (London), Human Factors, and Science. Results of the survey appear in Table 3. With the exception of Science, articles appearing in these journals infrequently cite NASA support. However, in conducting the review a number of articles originating in major aerospace contractor firms were noted which did not acknowledge NASA support. In addition, much of the Air Force supported research was also of direct concern to the NASA program. The Science survey is encouraging since there is an accelerating trend in the percentage represented by NASA supported publications (an increase from 0.3 to 1.7% over four successive six months' periods). Articles appearing in the other journals generally represent work completed up to a year or more previously while Science has a publication delay only a few months. These data are consistent with the hypothesis that it takes several years after the award of a research contract or grant before the work is prepared for publication - early publication of results may appear in Science many months before more extensive reports appear in the technical literature. The growth history of NASA grants and contracts in the life sciences suggests that the present rapid

TABLE 3

Journal and Period	Total No. of articles	NASA	Army	Air Force	Navy
J. Appl. Physiol.					
Jan.-June 1961	135	0	11	13	11
July-Dec. 1961	127	0	11	8	4
Jan.-June 1962	136	1	8	16	9
July-Dec. 1962	99	0	6	9	9
Jan.-June 1963	136	1	7	10	5
July-Sept. 1963*	81	1	5	8	4
J. Physiol. (London)					
vols. 155-167*	448	0	4	17	7
J. Neurophysiol.					
1960	53	0	1	3	1
1961	48	0	0	0	3
1962	50	0	4	4	3
1963*	61	0	1	9	0
Science					
Jan.-June 1962	290	1	8	3	7
July-Dec. 1962	326	2	12	7	15
Jan.-June 1963	498	4	9	5	17
July-Dec. 1963*	518	9	20	8	17
Human Factors					
1961	25	1	1	2	10
1962	37	0	3	4	13
1963*	28	0	1	7	3

*incomplete sample

increase in the number of Science type early reports will soon be followed by an acceleration of reports in life science specialty journals. If this prediction proves true, communication of space technology innovations to life scientists will be greatly improved. If an increase in the number of NASA supported publications is not observed in specialized life science journals, additional encouragement for such, through official policies, may be needed.

F. School of Aerospace Medicine Documents

While the formal journal literature in the life sciences has been growing in recent years, an even more rapid proliferation has been seen in the "technical reports" area. In the course of our study one recommendation which was repeatedly made by life scientists who were interviewed was that NASA establish a series of reports dealing strictly with bio-medicine (most interviewees were not NASA supported and were not aware of the relatively few biomedical reports issued by NASA to date). In order to estimate the possible usefulness of such a series, which might be distributed to any interested life scientist free of charge, an investigation was undertaken of the system presently used by the Air Force School of Aerospace Medicine.

1. Dissemination Procedures

The USAF School of Aerospace Medicine (SAM) Technical Documentary Reports are sent automatically to qualified requestors who are on the SAM mailing list. Individuals or organizations may become subscribers by completing a form (giving name and address and checking off which of 19 fields are of interest to the requestor). Most individuals and organizations are regarded as "qualified requestors". In addition, qualified requestors may send for specific SAM reports. Approximately 100 personal requests for documents are processed each month by SAM Publications Branch. The current mailing list for automatic distribution of SAM documents has increased to about 6000 names from 900 names in 1956. The New England area list contains approximately 200 names, of which about 75 appear to be non-military and non-missile industry requestors. In addition, SAM documents are automatically distributed to ASTIA, OTS, and are announced in the U. S. Government technical abstract bulletins.

2. Questionnaires

Since the SAM documents and their dissemination procedures represent a distinct form for the communication of aerospace research results to non-aerospace related life scientists, it was decided that the effectiveness of this method should be evaluated. Since it was impractical to survey all requestors, and since the use of these documents by the military or missile industry was not of concern to this study, only the 75 New England non-aerospace or military requestors were selected for the survey. It is recognized that this sample represents a geographically biased group, but the advantages of ease of follow-up appeared to justify this expediency.

A questionnaire was developed which would provide information concerning: a) how the recipients first learned of the SAM documents, b) whether they initially requested documents which they thought would relate to their own work, c) what documents, if any, have aided the requestor's research or practice, d) what documents, if any, have been cited by the requestor in a bibliography, and e) any general comments or suggestions regarding the SAM document form of communication.

3. Results

Of the 75 questionnaires sent out, 43 were returned (57%). Answers to the specific questions are listed below.

Question

1. How were you first made aware of the existence of SAM articles?
   Associate__________, Reference___________, Other (please explain)_______

Answers

14 responses listed associate

8 responses listed reference

1 response listed both reference and associate

20 responses listed other sources; 5 worked at SAM, 5 listed reprints or sample copies, 4 cited meetings or conferences, 4 cited courses at SAM 2 stated that they could not recall.

1 responder left this question blank.

Question

2. Did you initially believe that SAM research would relate to your work?
   Yes_________No_____________, Please explain______________________.

Answers

40 responded yes.

3 responded no.

Explanations were given by 11 of those surveyed (all but one of whom had answered yes to the first part). Explanations were:

Associate at SAM knew that work was of interest to me.

Generally related to own work

Interested in human factors and human engineering

" " pathology

" " periodontal research

" " psychiatry in aviation medicine

" " psychophysiology

" " radiological effects

Work at SAM was unknown before

Believed useful for teaching

Personnally interested (answered No to first part)

Question

3. Can you cite specific SAM papers which have aided your research or practice activities?

Answers

Complete, specific references:

SAM-TDR - 60-77	Shannon and Prigmore
SAM-TDR - 61-31	Prigmore and Shannon
SAM-TDR - 62-79	Shannon and Herter
SAM-TDR - 62-95	Shannon and Isbell
SAM-TDR - 63-63	Ulvedal, et al.
SAM-TDR - 63-53	Ulvedal, et al.

Fife - Importance of stomach and other extrathyroidal, extrarenal avenues of iodine loss during thyroid uptake tests.

SAM-TDR - 60-57	The effects from massive doses of high dose rate gamma radiation on mondeys
SAM-TDR - 62-29	A survey of C'p'd's for radiation protection
SAM-TDR - 62-39 - 62-46	Radiobiologic experiments in discoverer satellites XVIII

Instrument for measuring tooth mobility
Telemetry devices for dental research, Aug. 19, 1963

SAM-TDR - 63-27	Psychiatric aspects of simulator
SAM-TDR - 55- 1	Psychiatric aspects of simulator
SAM-TDR - 58-147	" " " "
SAM-TDR - 59- 4	" " " "
SAM-TDR - 59-11	" " " "
SAM-TDR - 59-12	" " " "
SAM-TDR - 5-59	sensory deprivation
SAM-TDR - 56-133	Expectation of food reward as the reinforcing agent in a learning situation
SAM-TDR - 57-52	Probability and statistics in item analysis and classification problems

The First International Symposium on Cardiology in Aviation

Ware, F., Effects of Co-deficiency and excess in frog heart, Aug. 1962

2. References identified by author or title:

Shannon's work in general was cited by five respondents

Welch's work on closed ecosystems

Hodges' work on discriminatory analysis

Gerathewohl's work on effects of weightless state

Cibis' work on toxic effects on retina

Lectures in Aerospace Medicine

Papers on stress in oral surgery

Papers on salivary gland physiology

Evaluation of Beles categories in space flight simulator

Biological systems of discoverer satellites XXIX and XXX

Annual reports of Space Medicine meetings

3. SAM's research areas cited as being useful:

Vertigo
Pulmonary studies
Allergic phenomena
CO in closed environments
Catecholamine measurement
Hypothermia
Earth's environmental conditions
Epitome of space medicine
Simulated Martian environment
Space biology
Stannous fluoride studies

Air bearing high speed endpiece
Psychology in general
Human factors
Human engineering
Endocrine reaction to stress
Drug effects on performance
Stress in dental patients
Chemical correlation and systemic status in periodonal disease
Surface contour changes after tooth extraction
Instrument for measuring horizontal tooth mobility
Development of telemetry device for dental research
Relationship of sulfate to initiation and rate of formation of bone
Measurement techniques (dental)
Dental Research

One respondent felt that his use of SAM documents was too extensive for listing, several stated that the reports they listed represented "just a few" of those which aided their research.

Question

4. Would you please list SAM reviews that you have used in a bibliography?

Answers

31 have not used any reviews in their bibliographies

12 have used reviews in their bibliographies

The following SAM reviews were identified:

SAM-TDR - 61-45, April, 1961, Prolonged hypothermia

SAM-TDR - 63-34, Task No. 775 801
SAM-TDR - 63-33, Task No. 583-002
SAM-TDR - 62-97, Task No. 27608

SAM-TDR - 61-106	Dental Caries and Systemic Status
SAM-TDR - 62-29	A Survey of Compounds for Radiation Protectic
SAM-TDR - 60-57	Effects from Massive Doses of High Rate Gamma Radiation on Monkeys

May, 1962 - Effect of Aqueous S_nF_2 on Enamel Solubility

Wheaton, J. L. - Sensory Deprivation Studies - Fact and Fancy

The following reviews were identified in a somewhat vague manner:

Study in which cold rats pressed a bar to turn on heat lamp for a brief period.
Fine structural changes in endocrine tissues during stress.
Plans are to use in a book on transfer.
Reviews used in bibliography are too numerous to list.
Used 15 SAM reports, but no SAM reviews.
Mostly lectures in Aerospace Medicine.

Two respondents indicated that they use SAM literature for teaching purposes. Their responses are quoted below:

"Salivary Gland Diseases (non-published) - a teaching file of slides and reports."
"Material has been used for teaching purposes."

Several respondents stated that while they had often made references to SAM reports, none of these were reviews.

Comments

Eight of the returned questionnaires included general comments on the SAM documents. These comments are quoted below:

1. "Find publication interesting and hope to continue to receive them."

2. "I use the SAM reports mostly as a way of maintaining some awareness

of developments in fields somewhat different in emphasis from that which is my primary interest."

3. "The quality of SAM papers are very good. I'd endorse their work highly."

4. "My main reason for continued interest in SAM activities is to continue my contact with aviation medicine, particularly as it applies to my present specialty of psychiatry."

5. "It is my impression that a more detailed card than is now used to classify recipients interests might be used. I receive both material which greatly interests me and material most distant from the area which I indicated on the yearly postcard."

6. "I am kept informed about many things I need to know about - its a good service."

7. "It is my opinion that the SAM reports are of extreme value in the Federal Government - Civilian sharing of research information."

8. "I appreciate receiving these issues and although several do not have direct pertinence to my work and research they provide good opportunity to evaluate related fields."

G. Communication of Research Results by NASA Grantees

At present the principle channels, other than Technical Reports, for the communication of research results from NASA sponsored studies at universities, institutions, or industrial laboratories are those adopted by the individual investigators. Information transfer through publication in the technical literature or personal contacts between scientists, is dependent on the individual grantee or contractor for implementation. Consequently, a knowledge of the communications habits of those grantees working in areas likely to have findings or innovations transferable into non-space related life sciences would be of value to this study.

A questionnaire was developed and sent to the principle investigators listed for 58 NASA research grants. Questionnaire recipients were selected on the basis of work statements which appeared to have possible transfer value into non-space related life sciences. Responses were received covering 36 (62 percent) of the research grants, although three of the responders returned blank questionnaires. * Thus information regarding communications habits of the investigators for 33 NASA research grants was obtained. These research grants had been in effect for varying periods of time, ranging from completion more than a year ago to initiation only four months prior to receiving the questionnaire. Questions and responses are listed in detail in Appendix A, and briefly summarized in the following paragraphs.

Large individual differences in amount and type of communications were noted among the questionnaire respondents. For example, 27 of the 33 who completed questionnaires indicated that their research results have been presented at one or more domestic or foreign scientific meetings or specialized

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* Explanations for not answering the questionnaire were:
a) No aerospace research scientists are utilized on our work for NASA (return from a large research firm).
b) not involved in biomedical research (return from a university space bio-science unit)
c) recently began program so naturally have no publications or reports (return from a university professor)

conferences or symposia. One investigator reported that his research results had been presented at 29 such meetings per year, while the mean and median values for all respondents were 3.3 and 1.6 meetings per year respectively. Only one of those respondents whose research results had not been presented at any meetings cited inadequate NASA funding for such attendance. Most responderts reported that NASA financial arrangements were adequate for attending meetings, but inadequate for foreign meetings. Reports of number of meetings attended, domestic or foreign, were not highly related to the reports of adequacy of financial arrangements for attendance at such meetings.

Six of the respondents indicated that their NASA sponsored research results have appeared in books, and two more indicated that manuscripts are currently in preparation. Nine respondents have had their work reported in commercial publications (newspaper, general magazines, etc.). Twenty respondents have published in scientific journals, or report articles in preparation or accepted for publication. Those respondents whose NASA sponsored research findings have been published generally report numerous requests for reprints, both from individuals working in their own discipline and in other disciplines. Publications cited by respondents totaled 7 in 1961, 12 in 1962, 18 in 1963 (up to November 1963), and an additional 17 in press or submitted for publication.

Those who returned the questionnaires generally discuss their work with from 2 to 30 colleagues per week (median of 5), and spend from 0.25 to 40 hours per week in such discussion (median of 5 hours per week.) These discussions were generally regarded as a valuable source of new information, although several respondees indicated that their colleagues do not supply any new information. Those scientists who do not obtain new information from their colleagues spend approximately the same amount of time in such discussions as those who do receive information. Number of NASA supported publications by these scientists did not appear to be dependent on communications with colleagues, visits to other institutions, or quality of available library facilities.

V. TRANSFER OF AEROSPACE TECHNOLOGY INTO THE LIFE SCIENCES

A. Representative Recent Technological Innovations in Biomedicine

Before considering the manner in which the space program has affected biomedicine, and the contributions which are anticipated, we shall review some trends in biomedical innovation. The innovations which have aided the advance of diagnostic and curative medicine in the past two decades have drawn heavily from the physical sciences and engineering. As Dr. Orr Reynolds has put it, "There has been no large industrial segment developed as a component of biological sciences as there has been in physics and chemistry. The state, therefore, of self generated technology for biology is low." (66)

1. Cardiopulmonary - Renal Physiology

Procedures for circulating blood outside the body, and the development of associated linear flow, pulsatile flow, and disk and bubble oxygenators, have come into extensive use for cardiac and neurosurgery and in the experimental laboratory.

The fluoroscopic amplifier has made possible contrast cinefluoroscopy, simultaneous viewing of radiographic investigations in progress by several observers, and decreased radiation dosage to patients and operators. Associated with this development has been the increasing use of rapid changers for sensitive radiographic film, for use in angiography (radiography of the heart).

The development of water-soluble angiographic media has been of great assistance in increasing the safety of these procedures.

The recent development of ultraminiature solid state circuits for telemetry, associated with an accelerated development in the field of physiological transducers, has produced encouraging results in applied physiological measurement in the field and laboratory.

A significant development in the analysis of electrocardiographic potentials has been the increasing use of vectorcardiographic methods along with continuing work on penetrating theoretical analysis of bioelectric field phenomena.

Thermal and isotope-dilution methods for the measurement of blood volume, and continuous recording techniques have made it possible to follow, clinically and in the laboratory, a variety of circulatory states (failure, shock), and their amelioration by therapeutic maneuvers.

Theoretical advances have been made in recent years, including some discussions of the Lapalace phenomenon with regard to the size of cardiac chambers, and the preliminary analysis of the function of the peripheral arterial system by means of analogue computer simulation. Recently, an analysis of the origin of cardiac sounds and murmurs, based on the Aeolean harp phenomenon (the vibration of strings as air flows by them) has been attempted with considerable success.

Cardiac catherization, although not new, has shown continuing development, and newer transducers have increased its effectiveness.

Open-heart surgery has progressed and the more complex valvuloplastices are now replacing the older valvulotomies in the treatment of valvular heart disease. The valves used are far from perfect, the major problem being intravalvular clotting and dissemination of emboli.

Phonocardiography has developed rapidly, and harmonic analysis of acousticardiac phenomena will undoubtedly prove helpful in diagnosis when its implications are fully understood.

An extremely significant development, supplementing the older developments of pacemakers, both implanted and external, is the increasing use of the precise placement of countershock during specific phases of the cardiac cycle. This has been shown to be effective in the reversion of atrial fibrillation (completely random rhythm in which the ventricular beat is linked loosely to a rapid atrial beat, and in which the atria do not contract effectively) to normal sinus rhythm, preventing the formation of and the dissemination of emboli from the feebly contracting atria.

Cardiac transplantation, both of muscle tissue and mechanical pumping mechanisms has proved feasible in the laboratory, and in a very few clinical cases. The major problem encountered to date has been that of clotting within the apparatus, and this will probably be solved by the development of the requisite lining materials and junction techniques, associated with more knowledge about the nature of the clotting mechanisms.

2. Respiratory Physiology Developments

Progress has been made in the analysis of the work of breathing, and its deficits in the injured or in patients with various degenerative diseases. The development of techniques for the analysis of respiration by the premature newborn is of the greatest significance in this respect.

Whole body plethysmography, continuous reading blood gas and blood pH apparatus, and single breath respiratory gas analysis equipment have made possible rapid determinations of respiratory parameters.

Angiography and plastic casts of the tracheobronchial tree and pulmonary circulatory system have broadened understanding of pulmonary physiology, and the evaluation of the effects of injury and surgery.

3. Hematology, Genetics, Metabolism.

Methods for recording red cell mass with radioisotopes, and of studying the decay of red cell structure have progressed apace, as has the development of rapid shunting techniques for clinical measurements.

A significant development in the cytological field has been the development of techniques for cytological genetic analysis which has delineated certain specific syndromes, and has provided some insight into mechanisms (Mongolism, Turner's syndromes, etc.)

The study of autoimmune mechanisms and their contribution to blood disease, and organ transplantation has produced some of the most significant medical advances in the last decade.

The study of the nature of DNA replication, and the possibility of introducing altered DNA into mammalian cells provides promise of major developments in the manipulation of the genetic material. This, associated with the development of techniques for the analysis of the genetic "code", and the careful delineation of known "molecular" diseases and metabolic disorders is the most active field in medicine today.

Improvement in analytical instruments and techniques introduced within the past few years have been essential to the progress in research and clinical practice in these areas.

a. Gas chromatography - for the analysis of small amounts of mixed materials, particularly steroids in recent years.

b. Counter-current distribution techniques - generally useful for the extraction of small fractions.

c. Diffusion immunoelectrophoresis - useful in assessing changes in protein structure with therapy and development, and for screening of individual differences.

d. Thin paper chromatography in two dimensions, coupled with radioisotopic analysis or mass spectrometry, has provided a potent analytic tool for the study of mixtures of biological materials.

e. Recent developments relating to the theoretical aspects of phase calculations in X-ray spectrometry has led to more precise analysis of hemoglobin structures.

f. Analysis of infra-red, ultraviolet, and Raman spectra have been successfully used evaluating the nature of biological materials.

4. Neurology, Ophthalmology, Anesthesiology

Probably the most significant development in neurosurgery has been the continuing work of establishing stereotaxic coordinates in man, and the use of these coordinates in refining "stereoencephalotomy" techniques. In addition routine techniques for the use of implanted electrodes in stimulation and recording have been successfully adapted from the laboratory to the operating room.

New surgical-related techniques have been developed to exploit the possibilities of producing in the brain (a) circumscribed lesions without the damage of intervening structures which must of necessity result from electrode or knife lesions; (b) reversible lesions by cold, drugs, and high temperature techniques; (c) new approaches to the closing of aneurysms.

Ophthalmic surgery has increasingly utilized photocoagulation techniques. The use of laser beams is producing major advances in retinal coagulation techniques, although other applications of the laser in microsurgery are equally promising.

Harmonic analysis of electroencephalographic phenomenon is now an accomplished fact, although its results have yet to produce important benefits in the fields of clinical and laboratory medicine.

Newer diagnostic techniques applied to neurosurgery include rapid angiographic techniques, and the use of radioactive arsenic perfusions of tumors to permit localization through measurement of emitted radiation.

Many new psychotropic drugs have been recently introduced. The speed up in evaluating the effects of new drugs on experimental animals is due, in part, to the use of operational techniques, and to the adaptation of digital computer systems for use in behavioral science studies.

5. Infectious Disease Developments

The most significant advance in recent years has been the production of a great variety of synthetic penicillins and their clinical evaluation. Some of these have proven to be effective and safe not only against resistant staphylococci, but against gram-negative organisms as well.

Viral diagnosis has become more usual, as tissue culture techniques, previously restricted to the laboratory, have been adapted for the clinical evaluation of acute infectious diseases.

6. General Surgery Developments

Very recently, total limb resuture has become a possibility. Reports indicate that some degree of return of function has been observed. New techniques for gastric surgery continue to appear, intragastric freezing being a recent promising innovation.

Dramatic developments have occurred in organ transplantation, neuro- and cardiac surgery, as has been mentioned previously.

B. Trends in Resources Available for Medical Engineering Innovations

These innovations have been made possible, in large measure by the availability during the last decade of significant increases in funds for both research and clinical medicine, and by the availability of increasing numbers of physical scientists and engineers and technician-level personnel.

According to the Department of Health, Education and Welfare, total public funds for health (as well as for education and welfare) more than doubled in the decade ending 1962, and the per capita increase in health expenditures rose by 60% (66a). Public appropriations for health have risen at least as fast, proportionately, as the national research and development budget (67) and in 1962, amounted to approximately $900 million. (68)

In addition to funds made available by the Department of Health, Education and Welfare for research and development in support of medicine, funds for care of patients have risen markedly in the past decade. Considering only those expenditures for health made in connection with hospitalization, cost per patient-day rose from $9. 14 in 1952 to $19. 73 in 1962. The greatest part of this increase went to increase in payroll of hospital staff (which rose from roughly 1.1 million employees to 1.8 million). Payroll costs per patient-day were $5.63 in 1952 and $13.12 in 1962.(69) It is not possible to identify how much of this added cost of payroll and non-payroll items resulted from introduction and wider use of innovations.

The great increase in the national budget for medical research, of course, also reflects the growing number of personnel engaged in this work. The Department of Health, Education and Welfare measured an increase over 100% in number of medical researchers in the six years ending in 1960. The 1960 breakdown was

Clinical specialties	10,305
Dentistry	610
Biosciences	17,160
Physical Sciences, Math. and Engineering	7,045
Social and Behavioral Sciences	3,255

There have always been physicians interested in the physical sciences and many of medicine's most significant innovations have resulted from a physician's "acting like" an engineer - the development of electrocardiography by Woller in the nineteenth century and electroencephalography in 1923 by Berger are two classic examples.

As has been frequently noted in this report, a highly significant development in medicine in the past decade has been the growing collaboration between scientists of different disciplines on a single project.

One dramatic case of the service of the physical sciences to medicine is in the use of electronic computers. Their application to medicine has been described in numerous reviews but their essential usefulness is perhaps best summarized by Dr. Frank Ervin, "A major characteristic of biological systems is the interaction of multiple non-linear probabilistic processes Imaginative experimentation, which has unraveled many of these, demonstrates that no amount of instrumentation will replace the creative scientist. On the other hand, the availability of data processing techniques makes it possible for the first time to investigate such processes directly. It is particularly in this field that biomedical sciences have an exciting challenge - and little experience." (70)

The marriage of engineering and medicine - in which NASA is to have so important a role - is reflected in the establishment of formal curricula for degrees in medical-engineering at Drexel Institute, University of Rochester, Case Institute, and other universities. Informal liaison between schools of engineering and medical centers is becoming commonplace, and agreements for cooperative research and development between hospitals and engineering concerns are numerous (71).

To be fully effective this permanent collaboration between engineering and medicine must offer both competences the opportunity for prestige and professional expression. Historically, the physical scientist or engineer has been the technical assistant to the physician, and the desire of many elements of the medical profession to maintain this relationship has been expressed by a writer in the Lancet:

"In this marriage of two disciplines, the partners, medicine and electronics, are so well balanced that the question will soon arise as to whom should be given the direction of new developments. The engineers have undoubtedly stimulated the traditionally conservative doctor, but if human beings are to be looked on as more than mechanical tools (inefficient ones, perhaps) final control must rest in the hands of the doctor" (72).

Resolution of the "conflict" between the historical attitude of the physician toward the "instrument maker", and the present-day need for fuller participation of the engineer in medicine, may have to await the development of a new generation of doctors who are sensitive to the engineering way of looking at a problem. Dr. M. C. Brown of NIH, surveying the effort of electronics technology upon medical education of tomorrow, observes that although, "the little black box (electronics) is only one part of the armamentorium of medical research today," it is directly affecting the criteria for selecting the next generation of medical students, their method of medical education, and their school facilities.

While the primary intent of this review of trends has been to identify the effect of the newer technologies upon medicine, the past decade has seen the great growth of the contribution made by the life sciences to engineering. In contrast to the older attitude that medicine's service to engineering consisted largely of identifying design hazards to health, today the work of neurophysiologists is providing objectives and guidelines for development of advanced self-adaptive computer systems modeled after the brain. More prosaic integration of the life sciences in engineering projects is represented in the paper by J. R. Pierce describing the important role played by the experimental psychologist (working with specialists in upper atmosphere physics, celestial mechanisms, computer application, etc.) in the successful design of the Telstar system (74).

C. Utilization of Space Science and Technology in Biomedicine

1. Introduction

The existence of the space program is affecting medicine and its supporting sciences in two general ways. The first is the development of information and hardware by biomedical specialties concerned with life in space which will further our understanding and control of life processes. The second influence of the space program is the work of its physical scientists and engineers who, in solving problems of instrumentation, materials, data processing, etc., are developing tools which can be borrowed by the life scientist.

We do not suggest that these "fallout" products of space activities can by themselves justify the expenditures of national resources which achievement of space goals demand. Nor do we suggest that the current study has provided data to permit a valid economic "evaluation" of the space program in terms of its contribution to human health. It can be argued that some or many of the innovations which will be described would have come into being without the aid of the space program, this is an objection which cannot be answered categorically. We can simply state that virtually all of the "cases" we have selected for inclusions in this report meet the criterion of having been caused by or significantly accelerated by the space program.

It should be pointed out that most of the advances to be cited are of the type that would not normally come to public attention. The public is accustomed to gauging medical progress in terms of improvements in cure or disease elimination. It is in the nature of the space program that curative medicine has a relatively small role. The philosophy is to select as candidates for space flight individuals who are "abnormally" resistant to the health threats of a hazardous occupation, and to design their task and their environment in such a way as to prevent the occurrence of disability. Although knowledge, instruments, and techniques developed in the space program may advance curative medicine, such applications will be secondary to the reasons for which they were developed.

Our analysis indicates that biologists, psychologists, and physcians engaged in space industries, together with their collaborators in the physical sciences and engineering, are making significant contributions to non-space life sciences in the following areas:

1. Study of the effects of the environment upon human health and performance and developing means of protection.

2. Establishment of ways of describing and measuring "normal health".

3. Investigation of the origins of life, and basic physiological mechanisms.

4. Development of improved tools for observing, recording and analyzing physiological processes and factors influencing them.

2. Study of the Effects of Environment upon Human Health and Performance and Developing Means of Protection.

Man must carry with him into space an environment which will enable him to survive and to perform his mission. He must also be equippped with means of protection against certain threats which are peculiar to space. Thus, in the manned space program life scientists have had to re-examine the fundamental question of man's relationship to his environment. Physical scientists and engineers have had to develop new tools to make this study possible, as well as designing the life support and protection hardware which the physiologists, physicians, and psychologists believe to be needed.

It is impossible at this thime to state with precision how much of the knowledge being developed will ultimately be applied to terrestrial problems of air and water pollution, care of hospital patients, etc. Among the several hundred specific problems being attached under the space program, the following appear to be particularly closely related to earth-bound problems:

Innovation Area 1: Atomosphere Contents, Pressure andTemperature.

Space vehicle crew members will breath "air" which has been stored on board prior to flight, or - on longer flights - is continuously generated by equipment in the vehicle. The breathable gas (or gas mixture) must be continuously monitored for quality. The principle new demand which space flight imposes is sustained endurance and reliability of the gas supply and contaminant removal system.

The problem faced by space flight surgeons and and life support system engineers is analagous to problems of the anesthesiologist. Beyond providing improved gas supply and monitoring equipment, the space program may make feasible the control of atmosphere for every hospitalized patient. "The suggestion has been made....that every patient be anesthetized upon admission to the hospital and kept asleep, sitting in a wheel chair in a room three feet wide, four feet deep, and five feet high until ready for discharge. In such a room, which would have no windows and only one door, atmospheric control would be a far simpler probelm than in a normal hospital room. It must be admitted, however, that there has been no general acceptance of such universal anesthesia. Nevertheless, for patients needing atmospheric therapy, this compact private room may be just the thing." (75)

The following are representative items of hardware originating in response to space program requirements which may make the atmosphere itself a general therapeutic tool:

Item: The PIAPAC system being developed under a NASA-OART contract by Lear-Seigler represents the most elaborate effort yet made to monitor a man's environment and his physiological response to it, and relate parameters of the two in a fairly rigorous fashion. This system is undoubtedly the forerunner of truly integrated human patient monitoring systems in which the control of the patient's physical environment would be based, in part, upon a continuous assessment of his response to it.

Item: The size, weight and reliability constraints of space flight have required intensive work on new trace-contaminant measurement hardware. (Reference 76 provides an excellent review of gas chomatographic, mass spectrographic and optical absorption equipment under development by manufacturers supported by the space program). Equipment developed by Bendix, Beckman, and others under the space program is now commercially available for research, anesthesiology, and industrial medicine.

Item: Trace amounts of "contaminants" in the space cabin environment may have significant effects upon the crew during their prolonged exposure to them. Conversely depriving the crew of certain atmospheric constituents to which earth has accustomed them may also adversely affect their health or performance. Hence the research being carried out under NASA sponsorship to determine the effects of "excess" and "deprivation" of certain components of air supply. (76)

No application of NASA supported research in this area has been identified, but anesthesiologists and persons concerned with industrial hygiene frequently referred to this work as having relevance to care of patients, and prevention of industrial health problems (77).

Item: Life support system engineers working on space suit and cabin atmosphere supply are concerned not only with the constituents of the environment, but also the air temperature and pressure Because of the requirements that the space vehicle crew be reasonably comfortable for long periods of time, and that they be able to move freely, outside the vehicle, the state of the art of pressure suit design has had to be considerably advanced. Components of currently available flight pressure suits have been used to provide external blood pumping assistance to patients with cardiovascular defects. Development of extracorporeal circulatory assistance is certain to benefit from application of techniques of pressure control now becoming available from the space program. A second general application of pressure suit technology in medicine has been proposed. The future hospital may provide equipment for patients who need "pressure therapy" (because of respiratory or cardiovascular difficulties), which permits them to be mobile while receiving external pressure assistance (75).

Item: Efforts to determine the effects of the environments of space, and of the ocean depths, have led to the development of a variety of types of pressure chambers for simulation experiments. The most noted clinical use of pressure chambers has been in "hyperbaric" oxygen therapy. Wyle Laboratories (El Segundo, California), for example, a supplier of environmental test equipment and services to the space program offers integrated chamber systems in which operations can be performed at pressures of several atmospheres. Cost of the Wyle Laboratory chamber system has been greatly reduced through use of novel techniques also utilized in Wyle's aerospace program activities.

Item: Important design and operating benefits would accrue to the manned space program if pure oxygen could be used as the space vehicle atmosphere, rather than using an atmosphere composed of several gases. The effects upon humans of prolonged exposure to pure oxygen were not well understood when the space program began, so that thorough investigation of oxygen toxicity has been undertaken under NASA and military sponsorship. At least one surgeon in the Boston area has kept in touch with information from the military on oxygen toxicity. Such major NASA projects as the Republic Aviation experiments, and the Lovelace Foundation synopsis and analysis of the state of the art of oxygen effects studies are too recently reported to have been widely disseminated within the medical community.

Innovation Area 2: Food Supply and Waste Handling

The duration of space flights to date have been brief enough to permit relatively simple solutions to food and waste handling problems. Flights of weeks and months will require that far more sophisticated approaches be made to provision of a truly closed ecological system. Before such a system becomes a reality, however, there must be a more detailed understanding of individual human nutrition, development of satisfactory novel types of food, and refinement in techniques of removing, and processing (or storing) human waste.

Item: Under NASA grant Drs. M. Winitz and W. L. Chan have developed a highly concentrated synthetic diet consisting of 18 highly purified amino acids, salts, and other substances in amounts presumed to have nutritional value. The diet appears to have had no adverse side effects upon the subjects who have subsisted on it for several months. Beyond being aware of the diet as a result of widespread publicity attending its experimental use in a California prison, food technologists have not responded to the innovation yet. If its use is found to have no long term ill effects, and if its cost can be reduced, the amino-acid diet could have widespread use as a supplement to the regular nutrition of population in less developed parts of the world.

Item: As in the case of atmosphere supply, NASA, military, and contractor scientists are concerned with trace constituents in food. The pre-planning of meals for long periods requires, ideally, that the body's total nutritional needs will be forseen and provided for. Hence there are several groups under space program sponsorship who are investigating the effects of trace amounts of materials upon health. We know of no clinical dietitians who are yet applying NASA sponsored research findings in this area, although their interest in such benefits of the space program is reflected in their interest in the low-residue diet studies and experience of NASA.

Item: While efforts to develop novel food sources (from algae, etc.) have attracted the attention of botanists, biochemicals, ecologists, less spectacular solutions to the probelm of food packaging and preparations have been proceeding (78). Several major corporations, including American Machine and Foundry, and Whirlpool have contracts in this area, and American Can Company has patented a food tube used in space flights (79). The economics of directly applying space flight food packaging preparation and preservatives techniques to the civilian market are unlikely except for such special situations as feeding of paralytics, and packaging of food supplies for sportsmen.

Item: Personal hygiene aboard space vehicles presents severe problems because of the constraints of vehicle design and the conditions of weightlessness. Removal of perspiration, urine, fecal and other waste products must be accomplished thoroughly and as conveniently as possible. Processing of this waste material to permit its re-use in the nutritional cycle is an ideal not yet realized in an operational sense. Equipment under development by Whirlpool and other contractors appears to provide a solution to the problem as it will be presented by Gemini and Apollo missions. The cost and inconvenience of human waste removal is of considerable importance to hospitals and convalescent homes. The technical feasibility of adopting space program technology to this problem is almost certain, but the economic feasibility of producing equipment to replace this function of the nursing aids is yet to be demonstrated.

Item: Personnel of the Manned Spacecraft Center of NASA are giving consideration to reducing the health hazard of stored or reprocessed human waste and reducing the possibility of contaminating extraterrestrial environments of discharged wastes by irradiating it before storage or discharge. Public health officers report that an increasing demand for their hygiene supervision services is being placed upon them by the growth in number of public swimming pools. A possible answer to the problem of poorly regulated chlorination characteristics of a large proportion of swimming pools would be to use small, low energy packaged bacteriocidal radioisotope units through which the water would be circulated.

Innovation Area 3: Effects of Motion, Acceleration and Weightlessness.

The advances provided by the space program in basic understanding of the effects of exotic environments will be reviewed in a later section. The present review will summarize the contributions by the space program in protection of man from adverse effects of motion and immobility.

Item: Space flight poses two deterrants to the healthful effects of man's normal activities. Confined to a space capsule, the crew have little opportunity to move freely, and the lack of gravity tends to increase the need for exercise. Physicians and physiologists of NASA, the military and their contractors have a number of studies underway directed toward developing ways of providing a way to avoid the potential de-conditioning effects of space flight. These include external pressure cuffs whose periodic inflation tends to maintain tonus of the cardiovascular system, and exercising devices and techniques to enable crew members to maintain muscular fitness. There has been a considerable amount of interchange between NASA, military and non-government physicians on the subject of effects of disuse, for the conditions of the astronaut in a cramped, weightless capsule is analagous to prolonged immobility required in some kinds of convalescence. While the most widespread by-product of NASA's research on the effects and prevention of disuse pathology will be in improving care of patients required to spend extensive periods of time immobile, the space capsule environment which places low demands upon the cardiovascular system has been suggested as a possible benefit to patients with cardiac conditions requiring "complete" rest (77).

Item: The shock, vibration and noise attendant to space flight have had to be coped with by engineers by lightweight seating and restraint systems, providing both protection from forces and reasonable comfort. NASA's contribution to this technology has been to facilitate and accelerate the evolution of personnel protection systems which have been under development by aircraft engineers for many years. The seat belt design and configurations which are widely used in automobiles today are byproducts of the simple restraint device development which accompanied the growth of airline travel. While the design of automobiles has not fully utilized the available technology of passengers protection, space program developments in energy absorbing materials and designs may be used in future private and public conveyances, if the public's interest in self preservation while traveling continues to grow.

Item: The experience of Russian cosmonaut Titov in orbital flight included attacks of dizziness and nausea similar to the symptoms of seasickness. This development increased the concern of NASA and military groups about possible threat to the health and performance of ast ronauts. Under NASA fundings, the Navy and other contractors have expanded research on the causes, mechanisms and effects of motion sickness. The work of aeromedical specialists in vestibular physiology has been widely disseminated in the physiological and behavioral science communities. The unique Slow Rotating Room of the U. S. Naval School of Aviation Medicine is among the most frequently identified facilities of the aerospace medicine program.

Innovation Area 4: The Radiation Environment

Item: In section III the contributions of the space program toward understanding the mechanisms of space radiation effects were summarized. The most dramatic application of this recent advance in understanding of the effects of radiation has been in heavy particle radiation therapy.

Item: Other developments in radiation science and technology fostered by the space program include design and development of lightweight shielding materials, improvements in shielding calculations, and research in anti-radiation drugs. No direct transfer has been identified at the present time, because many of the constraints of weight and volume which are of concern to space engineers do not exist in the non-space clinical environment, but if breakthroughs affecting the cost of production of radiation shielding were to be achieved, for example, or if anti-radiation drugs were perfected, clinical radiology could be greatly assisted.

Innovation Area 5: Effects of the Sensory and Social Environments

Item: Development of highly integrated simulation facilities under space program sponsorship has provided experimental tools and methodologies for studying the "subjective" effects of confinement and other sensory and social stresses. Representative of the meaning of this work to the behavioral science community are contributions to the sensory deprivation literature and development of methods of measuring effectiveness of small groups. Persons engaged in geriatrics and in rehabilitation of the blind are particularly interested in the space program's work in sensory environment simulation, for they are concerned with assisting their patients to maintain contact with "reality" and maximize useful interaction with the environment.

Other applications to industrial and other branches of applied psychology include maintenance of alertness in boring (but vital) system monitoring tasks, and selecting and training small groups of workers.

3. Development of Ways of Describing and Measuring "Normal Health"

Innovation Area 6: Development of Procedures for Gathering and Processing Data Concerning Ability of a Man to Carry Out a Job.

Item: The manned space flight program has generated the requirement for screening and selecting individuals who will be able to endure the demands of space flight. The intensive screening procedure used in selection of the original seven astronauts has been demonstrated to have been satisfactory. In addition to the very thoroughness of the screening examination, innovations have been made in the area of data recording and analysis (80). The procedures (and hardware) used in observing the parameters of health of subjects have application in public health. While the data needs of public health and space medicine differ in important respects (public health needing, typically, relatively small amounts of data from large numbers of subjects, and space medicine demanding large amounts of data from small numbers of subjects), the integrated approach of stimulus - response recording and data analysis has relevance to development of similar system concepts for public health.

Innovation Area 7: Generation of large amounts of data on healthy persons, stressed and unstressed, acute and longitudinal.

Item: Dr. Charles Berry of the Manned Spacecraft Center is quoted as describing the wide range of "normal" responses which have been recorded under stresses of space flight, both during flight simulation on earth and during actual flight. The wide range of physiological data recorded during the program, especially heart rate, have modified the understanding of "normal" (79). The recent symposium on stress, attended by many of the world's leading physiologists (81), and papers presented by aeromedical specialists at the Winter 1964 meeting of the American College of Cardiology on the cardiovascular effects of environmental stress (79) are signs of a growing interest in research, industrial medicine and general practice in the response of the body to stress. It can be expected that the data, procedures and equipment (especially telemetry) from space medicine will importantly affect medicine. A contribution of viewpoint as well as technique has been expressed by Dr. W. R. Lovelace, "In contrast to clinical medicine, where the stressing agent is disease, in aerospace medicine the stressing agent on the normal subject is the environment." (82)

A still elusive, but sought-after goal of space medicine is the reduction of parameters monitored to one or two whose values can be used as indices of overall present and probable future health. Beyond this goal lies the objective of understanding the relation between physiological values and mental performance capability. Lt. Col. David G. Simons, a well know Air Force flight surgeon and scientist, concluded a description of the information Project Manhigh* provided

*Project Manhigh was a series of extremely high altitude balloon flights.

on man's response to the stress of space flight by stating, "The Manhigh program was born of the challenge beyond: Space. I believe the lessons learned in that program define a new challenge: the challenge within, this is the challenge of relating the performance of the mind with the function of the body. This can only be done through a rigorous step-by-step neurophysiological understanding of how the mind works. Modern brain research and electronic advances open new paths into this frontier. Advances here are essential for space medicine and promise great benefit to all medical science". (83)

4. Investigation of the Origins of Life and Basic Physiological Mechanisms.

The basic research of NASA in the life sciences has two objectives. The first is to provide the information needed by the operational medical personnel of NASA (those responsible for the health of the crew), the engineers who must design the system to sustain the astronaut's life, and by the engineers responsible for maximizing the efficiency of the man-machine system which will explore and operate in space. In addition to this "mission-oriented" research NASA has been given a responsibility to advance understanding of life processes. Clearly these are not two entirely separate objectives. For example, experiments directed toward determining how well a man can use vision to guide the rendezvous operation also reveals previously unmeasured qualities of human depth-perception mechanism.

Innovation Area 8: Ecology

NASA and military managers of the space program have greatly accelerated research in ecology. While adventurers at sea, in the Arctic, etc. have always had to synthesize an environment upon which to subsist, typically nature provided the greater part of what was needed, and man had only to make relatively minor adjustments to it in order to survive. Travel in space presents a challenge to man's ingenuity far different in scale to any ecological problem-solving done before. Hence the tremendous need for information about the requirements for life support.

Save for specific solutions to problems of nutrition, atmosphere supply, etc. suggested earlier, the main impact of the space program in ecology will be its stimulation of interest in this fundamental science, and under its sponsorship the development of methodology (e.g. mathematical simulation of ecological systems) and research results (84).

Innovation Area 9: Exobiology

Manfred Eimer of Jet Propulsion Laboratory identifies four questions whose answers may only be obtained through study of biology beyond the earth:

1. Are there fundamental general laws of biology in addition to that of evolution?

2. What was the principal source of pre-biotic nutrients?

3. What were the first self-replicating polymers?

4. Are nucleic acids a general solution to the genetic problem? (85)

Thus the study of biology beyond the constraints which our earth has placed upon the origination and development of life may reveal not only the existence of extraterrestrial life, but may shed unique light on how life began on earth (84). Terrestrial laboratory experiments supported by NASA as background for space experiments are already yielding significant contributions to biology. Representative of these was the synthesis in 1963 of adenosine triphosphate (ATP) by Sagan and Ponnamperuma under Ames Research Center sponsorship.

As early as 1960 the life science community was asked by NASA to recommend the format of the exobiology program. In June of that year some 35 participants representing biology departments of 14 leading universities and major government life science laboratories met to discuss the meaning of the challenge and opportunity presented by the space program, and to draw up guide lines for extraterrestrial biological investigations (86); this input from the non-space research community has continued. Thus it can be expected that the results of space biology experiments will be rapidly incorporated into the existing body of biological knowledge.

Innovation Area 10: Basic Physiological and Psychological Research

Activities of the space program in basic biological and behavioral research are too diverse in nature, scale and "importance" to be readily summarized. The following items, therefore, are presented simply as representative of NASA's contributors to understanding of fundamental mechanisms.

Item: The influence of gravity upon living systems is the one factor which cannot be thoroughly isolated upon earth. Indicative of our ignorance of the role of gravity in human physiology and psychology were the predictions of capable physiologists in the early 1950's that man simply could not adopt to weightlessness. Space travel for periods of nearly a week has now been demonstrated to be feasible, but we still lack the theoretical basis needed to predict whether man can tolerate many weeks of living without gravity. The adaptive responses of physiological subsystems to zero-gravity may reveal much about the basic influence of gravity which in time may contribute to better care of the physiological subsystems when disease attacks.

Item: In the early days of the space program is was suggested that space crews might benefit from being induced into a state of hibernation in order to reduce their nutritional requirements and improve their resistance to space radiation. This extreme operational measure is rarely suggested today, but research on the effects of low temperature on living systems has been greatly stimulated by space program support. Advances in "cryobiology" have been assisted by the refinement of cryogenic experimental system originally developed for missile systems. Garrett Corporation for example, has announced undertaking application of its cryogenics capability to problems of cryobiology involved in food preservatives, neurological and intestinal surgery, and organ transplant (79).

Item: The fact that living organisms exhibit regular daily cycles of physiological change has been known for many years, and its operational implications have been examined in connection with submarine and other military operations. As is the case in so many other instances, however, diurnal variations may be of much greater importance to space travelers. The research being supported by NASA and the Air Force on the effects of changes in length of "day" has already had an effect upon the medical advice given to airline passengers making jet-speed long distance flights, and may in time contribute to industrial medicine's future problems of advising how best to distribute the few working hours per day.

Item: Implicit in much of the foregoing discussion is the significance of the satellite as an experimental facility. Under its bioscience programs NASA and the Air Force have offered qualified investigators the opportunity of having experiments of their own design flown in missile nose-cones and in satellites. The Air Force, for example, has sponsored space flights of numerous biological materials to determine effects of cosmic radiation, and (by using internally instrumented animals) has provided data on subtle effects of the space environment upon cardiovascular and pulmonary systems. NASA's biosatellite program will include a variety of experiments in botany, cardiovascular physiology, neurophysiology and behavioral sciences. The screening of nearly 200 experiments proposed by non-government life scientists to select about 40 will be done by a special group of NASA's science advisory committee representing the spectrum of interests in the life science community (79).

In addition to providing a limited number of biological and behavioral scientists with the opportunity to conduct experiments in space laboratories, the space program is providing funds for the establishment of elaborate laboratory facilities at government installations, contractor plants and in universities. While the immediate demands of the space program for physical science and engineering data exceeds available time on centrifuges, in environmental test chambers, etc. it is reasonable to expect that later in this decade more and more use will be made of these facilities by bio-scientists for experimental work unrelated to the space program. (In fact, as will be noted in concluding sections of this report, the inventory of experimental equipment and facilities being accumulated under the space program may be one of the most significant contributions to the life sciences to have been made by NASA).

5. Development of Materials, Components, Systems and Methods Applicable to Medical Needs.

It is natural that the many observers who have enumerated the expected by-product benefits of the space program have typically identified advances in medical hardware as a key example. Those who have sought to add up the specific instances in which space-derived products are being used in medicine today have generally produced a dismal picture of impact. Briefly, we believe the reasons to be the following:

1. NASA's greatest direct contribution to medicine will not be through providing new hardware, but through stimulating the development of medicine itself - in the areas such as those which have been discussed above.

2. The hardware development which has occurred has contributed to engineering in medicine, which is still an infinitesimally small part of medical research and practice. The life sciences have traditionally been poor customers for products based upon advances in the physical sciences and engineering.

3. The emphasis in innovation acceptance in medicine is upon innovation in treating patients. Most of the hardware developed under the space program however, is useful for observing individuals, not treating them.

While we do not have figures to justify the assertion, it is our belief that NIH is spending considerably more for development of medicine-related equipment than are NASA and the military space programs, with one important exception: development of life support hardware (environmental control systems, pressure suits, etc.).

Thus in the advance of science and technology in materials, components, systems and methods, for use in medical research and practice, NASA's contribution of specific items is not likely to be as significant as the contribution of its activities in the physical sciences and engineering are in advancing the state of arts from which engineers in the industries serving medicine directly can draw. The following items represent both kinds of effects; some of the instances of transfer cited below represent hardware designed for space program use which is now in use in medicine, others represent the larger class of transfer in which space-supported technical activity has produced something which has been modified by a bio-engineer and incorporated into research or clinical equipment. The items are grouped under the innovation area headings of:

Physiological sensors
Environmental sensors
Signal conditioning, Transmission and Receiving, Display and Data Analysis
Therapy
General

Item: "An electromagnetic flow meter originally developed for the missile industry is being used at UCLA to diagnose erratic heart action that otherwise may be difficult to detect" (79).

Item: In addition to sensing the dynamics of physiology during flight, it would be highly desirable on longer flights to collect and analyze biological specimens - blood, expired air, urine, etc. An example of developments in this area is the Bio-Telescanner developed at the USAF School of Aerospace Medicine (90). The device incorporates a photocell - scanner mechanism which detects precipitation resulting from antigen-antibody reaction in specimen fluids, and reports the density of the reaction. Automatic analysis devices of this type can have wide application in public health.

Item: Representative of the advance of medical instrumentation made possible by use of components developed or refined in the space program is the ballisto cardiograph (termed the "Ballisticor") now offered by Cordis Corporation (Miami). The problem of isolating the patient from external vibration while the accelerative forces of his heart are being measured was solved by incorporating a gas bearing originally used in the missile program. The inventor (W. E. Rothe, Huntsville, Alabama) also included strain gage accelerometers in his design.

Innovation Area 11: Physiological Sensors

The space program and the military aviation program upon which it is based considers the health and safety of the system operator as a dominant design and operational criteria. Implicit in this philosophy is the desire to continuously assess the well being of the remote crew by observing his physiological responses to the challenges of his task and the environment. The condition of space flight requires that sensing of physiological values be performed for long periods of time, reliably, with minimum interference to the crew and minimum effect upon system weight and volume.

Item: Since the condition of the cardiovascular system is of vital significance to health, and since its condition can be fairly well assessed by observing the patterns of electrical activity (the EKG) which accompanies heart actions, considerable attention has been given to design of electrodes for recording these patterns. Electrodes developed under sponsorship of the Air Force and NASA represent great advances, and are probably the best known medical equipment development of the space medicine program. (87, 88, 89)

Item: Under space program sponsorship, Geddes of Baylor University demonstrated the feasibility of monitoring respiration by observing electrophysiological variations which accompany breathing. Introduction of this method into the manned space program displaced other respiration monitoring methods which had been considerably advanced by the aviation and space medicine program: detecting breath and flow by a thermister, or by an electric chest band upon which a strain gage is mounted. The pulmonary physiologist can now obtain commercial hardware to monitor breathing by any of their methods.

Item: Blood pressure has long been accepted as a key parameter of health, and because of the expected changes in cardiovascular dynamics produced by weightlessness, monitoring of blood pressure has been the subject of a considerable amount of space medical-engineering effort. In 1961 Webb Associates surveyed the state of the art in blood pressure sensing systems for NASA and identified four approaches which appeared promising for Mercury program application, with six others identified as probably unfruitful for space use (79). In-flight blood pressure monitoring equipment developed at the U. S. Air Force School of Aerospace Medicine (Roman and Ware) was found by our project staff to have been considered by personnel of a large city health department, a medical school, and a potential manufacturer to have great promise for non-space clinical examinations.

Item: Under space program stimulus engineers and physiologists are not only exploring new ways of measuring "standard" parameters (like blood pressure) but are investigating other variables which have been ignored by clinical medicine. The cardiovascular system whose operation produces electrical signals, vibrations, pressures and other energies is rich with potential for measurement. One that appears to have particular promise is the measurement of acoustic properties of flowing blood. Pulse wave velocity (PWV) determinations may become a routine clinical test.

Innovation Area 12: Environmental Sensors

Earlier in the discussion of the life support problem faced in the space program, the need for accurate analysis and control of the environment was cited. Environment control is based upon sensing of the present concentration of atmosphere constituents, their pressure and other characteristics. Environmental sensing is also of importance in a number of non-space situations such as industrial hygiene and anesthesiology.

Item: Beckman Instruments, Inc. developed and marketed a polarographic oxygen analyzer with company funds. While the basic equipment was company sponsored, application of the device for use in the Mercury program required that it be made smaller, with lower power consumption and faster response. Present-generation equipment, incorporating these space-stimulated improvements is being used in a variety of medical and industrial oxygen analysis applications.

Item: Another oxygen analysis instrument using the principle of polarography was developed by J. R. Neville while on the staff of the Air Force School of Aviation Medicine. Used at the School in monitoring the capsule environment in the "Little Joe" biopack flights, as an hypoxia warning device in aircraft and in studies of metabolism, the device is now licensed for commercial sale.

Item: Bendix Corporation markets a portable time-of-flight mass spectrometer developed for use at the Air Force Aeromedical Research Laboratory for research and process control problems involving gas analysis.

Innovation Area 13: Signal Conditioning, Transmission, Display and Data Analysis

Item: Development of miniature physiological data telemetry equipment is probably the best known contribution of the aerospace program to medicine. Still there are relatively few systems in use at the present time - no more than 500 as well as we can estimate. Though there are at least ten firms which advertise such equipment, routine "radio-cardiographs" are not yet accepted as standard clinical practice.

Item: Visualization of internal physiological phenomena has advaned markedly with the development of "Thermography" - display of the heat emmission patterns of the body. Sales literature of the Barner Engineering Company states that, "In medicine, the (infra-red) camera is now showing possibility as a new, non-contact, non-destructive tool for the diagnostician, pathologist and internist. By detecting 'hot spots' in the human body, the camera can suggest the presence of malignancies and other pathological conditions" (91).

The technology needed to provide medical infra-red visualization equipment was developed largely as a result of such space program requirements as radiometers for satellites, horizon sensors and a variety of military needs for detection systems based upon thermal sensing (92).

Item: Several aerospace program contractors have addressed the problem of displaying the three-dimensional information generated by vectrocardiography (VCG). ITT has described adaptation of techniques originally developed for 3-D display in airport traffic control to VCG display, and Ling-Temco-Vought has applied a 3-D display concept developed for display of vehicle position to the problem of VCG presentation.

Item: McDonnell advertises a signal correlator developed for use in aerodynamics experiments as an instrument capable of (inexpensively) assisting physiologists in observing, in real time, the statistical correlation between variables being monitored.

Innovation Area 14: Therapy

Item: The dramatic affectiveness of "cryosurgery" in treatment of neurological disorders and in ulcer therapy has been made possible by the low-temperature technology advances achieved under missile and space program sponsorship. One of the leading suppliers of equipment for cryosurgery, Linde, is also contractor for infra-red sensor cooling equipment and other devices for precise low-temperature control of small elements.

Item: While the idea of "automatic" syringe injection of drugs did not originate with the space program, the devices developed under NASA sponsorship represent innovations in ruggedness and reliability of operation. Their use in hospitals is not forseen, but they appear to have applications in the medical program of Civil Defense and Public Health in remote areas.

Item: Use of a Gulton accelerometer in sensing a Parkinson Disease patient's tremor has been demonstrated to be a valuable aid to the neurosurgeon. By observing changes in pattern of tremor during the brain-lesion operations, the surgeon can more readily select the site of the lesion to be made, and monitor the effect of the lesion (93).

Item: The Missile and Space Division of General Electric is one of several NASA and military contractors investigating the feasibility of drawing electric power from the metabolic activity of living organisms. In 1963 a physical biology scientist of G. E. sponsored by NASA derived approximately 150 microwatts of electrical power from the body of a live rat, and used it to energize a transmitter. While the immediate application of body-powered transmitters will be in physiological research, continued development of "bio-batteries" may make it possible to power implanted prosthetic devices (pacemakers, artificial muscles, etc.) with the human body's own electrical energy.

Innovation Area 15: General Effects of Space Program Technology

The foregoing sections have summarized some of the instances in which the existence of the space program has affected research and practice in the fields of medicine. We expect that a similar survey made in successive future years would reveal an exponential increase in the number of cases which could be described. However, the citation of specific cases of fairly direct transfer of scientific and technological innovations from the space program into medicine does not adequately describe the impact of the space program: there are more general and diffuse ways in which the existence of the space existence of the space effort expresses itself.

Item: The term "systems approach" has been used so often in the missile and space program that it has become almost meaningless. Yet the concept it describes is fundamentally novel in the life sciences. Aeromedicine pioneered in application of systems engineering to solution of medical problems - defining requirements for life support equipment, and evaluating and approving designs in close liasion with engineers. Three examples of latter day systems approach to clinical problems will illustrate this area of technology transfer: Dentistry has been characterized by a greater willingness to adopt advances in technology than most other fields of medicine; in part this is because the problems of diagnosis and healing faced by the dentist fairly clearly dictate the forms of task, and the direction of their improvement. However system engineering is seldom seen in dental equipment design. A recently developed modularized concept of dental equipment design for clinical use may represent an important contribution to dental medicine. Dr. W. E. Burton described the system to the American Dental Association's October 1963 meeting; Lockheed Aircraft was reported to be one of the firms interested in manufacturing it (94). Claiming that much of the equipment used in dental practice is inherently resistant to thorough sterilization, he proposes an integrated system of tools, lighting, seating, etc. whose components can be reasily disassembled and sterilized.

For several years Dr. Hugh McGuire of Montgomery, Alabama has been actively engaged in the promotion of a system-engineered hospital concept. In his "Automedic" hospital there is great attention given to optimum allocation of tasks to men and machines, with equipment and operating procedures designed to relieve professional personnel of routine, sub-professional tasks.

The disappointment expressed by many hospital administrators in the failure of first-generation physiological monitoring systems to fulfill their expectations was evidence of poor systems engineering. Much of the "integrated" physiological monitoring equipment installed three to five years ago was unrealistically sophisticated; not enough attention was given to training, maintenance, and integration of the equipment with the existing hardware and procedures.

A physiological monitoring system now in use in a New Jersey hospital represents this evolution of design from space application to research-center use to general clinical operation. For several years Gulton Industries has supplied to NASA and the military components and systems for physiological data gathering. Working with research physicians and engineers at the National Institutes of Health the firm also developed and installed an integrated physiological data acquisition system for monitoring patients under intensive care.

Subsequently Gulton, and its marketing partner, Executone, Inc. contracted to install a similar system in a New Jersey hospital. While the data sensing and recording requirements of the application were, relatively simple compared with aerospace and research medicine installations, the firm had to meet three severe criteria: simplicity of operation, reliability and patient comfort. The wired system senses and records patients' systolic and diastolic blood pressure, pulse rate, and respiration rate; it can be expanded to include other parameters.

The collaboration of Executone, Inc. and Gulton Industries in designing and marketing hospital monitoring systems highlights the necessity of integrating advanced engineering with a substantial sales and service resource in order to effect the transfer of space technology into clinical medicine.

Item: The space program is providing a stimulus for development of a strong biotechnology industry capable of addressing medical needs such as those to be discussed in the next section. Prior to the advent of the manned space program, medical engineering capabilities were possessed by few industrial concerns. Today most of the larger space program contractors have departments of bio-engineering, headed in many cases by life scientists having engineering experience.

In the early days of the space program some leaders in the life sciences expressed concern that the funding to be made available for space medicine and related research would divert talent away from badly needed non-space medical research and engineering. This has not been the case; in fact a criticism that not enough of the nation's top life science talent has been attracted to space problems is now occasionally voiced.

D. Needs of Medicine for Technological Innovation

The proceeding sections of this discussion of the impact of the space program upon biomedicine have suggested the ways in which research and clinical medicine of the future may reflect the activities of NASA. New biological knowledge will flow from space projects, new attitudes of "systems approach" will be seen, and integrated medical-engineering team efforts will be more common. A medical hardware industry will develop which will be populated by many smaller firms, and, perhaps, some airframe manufacturers who were "capitalized" by space medicine contracts. Beyond these effects of the space program, the quality of engineering service to medical research and practice will improve as a result of the availability of technology which has been developed under the space program. Sophisticated design solutions to medical problems of long standing are bound to result from the application of space-derived materials, components, subsystem design, and engineering practices.

The following problems are illustrative of the needs of medicine for use of state-of-the-art technology and ingenuity which has characterized engineering efforts of the space and missile programs. Those life scientists who contributed to the building of this list are of the opinion that none of these problems needs a life-science breakthrough; their solution will be the product of sufficient engineering attention and funds. This "shopping list" is arranged under the headings of:

1. Sensing physiological phenomena
2. Visualization of physiological system components and operation
3. Sampling and analysis of biological specimens
4. Aids to recognition of physiological states and patterns
5. Tools for research and clinical treatment
6. Replacement parts.

1. Sensing Physiological Phenomena

Data acquisition for biology has much in common with that of other sciences but in general the differences between the physical and life sciences prohibit direct transfer of techniques from one to the other. As in other fields, data acquisition in biology consists of transduction of energy imparted by the phenomenon under study, conditioning of the transduced signal and recording of its characteristics. In none of these three areas has there been sufficient special design for the biologist; in nearly all cases, methods have been borrowed from the physical sciences. Although this borrowing has not been indiscriminate there have nevertheless been two unfortunate effects of it. One, the transducers rarely fit all the needs of the investigator and two, the course of research all to frequently is dictated by the types of conditioning and recording equipment available.

The types of specifications applied to transducers used in medicine are much the same as those to which engineers have become accustomed. They include frequency response, linearity, stability and freedom from inherent distortion. In addition there is the essential requirement that the transducer shall not unduly interfere with the process or organisms being studied. While this requirement is implicitly present in all instrumentation, it becomes particularly troublesome when the entire system under investigation is measured in microns, or is an ailing person.

Although transducer selection in biology is done mainly on the basis of physical specifications, attention must also be paid to other factors which rarely, if ever, enter the engineering world. If used on conscious subjects, a transducer must be comfortable; if used in surgery, it must be sterilizable; most transducers must be free of allergenic materials. As if these qualitative criteria were not enough, some transducers must have their response deliberately restricted so as to measure not the actual response of the subject, but rather the response as it has been observed, so that the data can be compared with historical norms.

Item: Indirect Blood Pressure

When a patient's blood pressure is taken, two kinds of inferences are possible. The first has to do with the possible causes of abnormal pressure and the second concerns its potential consequences. The first is thus diagnostic and the second prognostic. The use of blood pressure data has therefore become deeply embedded in clinical routine. Methods that allow the blood itself to contact a transducer are called direct blood pressure measurements. In conjunction with major sugery such measurements are made, but for post-operative and general clinical care indirect means are preferred.

Most indirect measures of blood pressure involve the occlusion of an artery, usually by a flexible pneumatic cuff. As the cuff pressure varies from zero to above the maximum, changes in the sound (auscultation method), color (flush-throb method) or volume (plethysmographic method) of the limb or digit are noted and can be related to the minimum and maximum pressures associated with each beat of the heart.

The main disadvantage of these schemes is that such measurements can be made only on an intermittent basis, lest the flow of blood to the tissue distal to the cuff be cut off too long. Not only does this prohibit continuous monitoring but it implies a sequence of operations which is long and during which several measurements must be made. Automatic equipment based upon these types of indirect measurements is complex, and manual techniques require considerable skill for reliable readings. No automatic device has reached general acceptability.

Methods of making indirect pressure measurements without arterial occlusion have been devised and must be improved. They depend upon one of the following physiologic parameters which are known to vary with blood pressure.

-velocity of the pressure pulse
-velocity of sound in the blood
-blood flow volume per unit time
-distension of the artery and the overlying skin

Each of these methods has its characteristic faults. To improve patient monitoring, to conserve the time of doctors and nurses, and to detect emotional reactions, and improved means of blood pressure measurement is much needed.

Item: Blood Flow

Closely related to the need for accurate blood pressure is the desirability of measuring local blood flow. Such knowledge not only reveals anomalies in the vascular system but also tells much about the body's ability to respond to stress. Existing blood flow meters function on the basis of manometric measurements, radio-tracers, dye dilution, Farady effect, Doppler effect, nuclear magnetic resonance, and the insertion of rotary devices into the blood stream through suitable connecting tubes. All of these methods suffer from one or both of the following defects.

a) they interfere with the flow.
b) they require intimate contact with, or insertion into, the vascular system.

Ideally, one would like to measure the blood flow in a specific unexposed blood vessel (e.g., the brachial artery, the common carotid artery, the pulmonary artery and pulmonary vein, the renal artery) and in an intact limb.

Item: Free Blood Volume

In the diagnosis of certain circulatory diseases and especially in the determination of the degree of shock, it is highly desirable to know the amount of blood which is free to circulate, i. e. not pooled in the liver or spleen or other major organs. The chief present technique has been used by a few years; it consists of the injection of a radioisotope, usually gold or chromium, and the measurement of its dispersion in a blood sample taken a few minutes later. A better method would be one in which the injectate would be selectively bound to specific blood constituents and in which measurements could be taken continuously or at least every few minutes.

Item: Surface Electrodes

The measurement of bio-electric potentials is widely used in medicine and psychophysiology in both clinical and research situations. Electrical noise associated with such measurement systems frequently occurs as an electrode artifact.

Item: Glaucoma Detection

Intraocular pressure must be sensed without injury to the eye, and safely and rapidly enough to permit large scale screening of the population.

Item: Cerebrospinal Fluid Pressure

In neurosurgical and laboratory procedures, a method is needed for continuously recording the spinal fluid pressure.

Item: Improved Pulmonary Function Tests

Rapid detection of breathing work and breath patterns changes will be needed to meet the accelerating pace of research into the effects of chronic and acute exposure to atmospheric contaminants, by both healthy persons and by persons with cardiovascular or respiratory impairment.

2. Visualization of Physiological System Components and Their Operations

Item: Methods of Visualizing Soft-Tissue Organs

Ultrasonic systems have recently been made commercially available (and used, for example, in examination of the brain - "echo encephology") but improvements are needed to facilitate viewing the lymphatic system (to detect metastases), the liver, pancreas, and spleen. Ingestion of radio-opaque fluids by the patient in order to make soft tissue organs visible via x-radiation does not appear to be a satisfactory long-range answer to the problem of viewing soft tissue organs.

Item: Direct Viewing of Organs

Recent developments in fiber optics and ultra-miniaturized TV camera tubes point the way to direct viewing of the internal structure and operation of organs. Further miniaturization, solution of the problem of tissue damage, and, finally, precise and reliable control of the sensing device must be achieved before this potentially valuable tool of diagnosis can become practical. Development of external control of viewing devices should also enable the diagnostician to sample temperature, pressures and other physiochemical properties of internal organs in-situ.

Item: Rapid Fluroscopic Screening

Improvements in radiographic equipment during the last decade, and refinement of image intensifiers have greatly facilitated fluroscopic screening, and reduced the radiation exposure of the patient. Further advances in display technology will permit rapid examination in mass (Public Health) screening.

3. Sampling and Analysis of Biological Specimens

Item: Ionic Analysis

The semi-permeable membranes of the body function largely to preserve the tonicity of the body fluids. In disease, the fluid balance is a subtle indicator of condition. Quick and convenient means of quantitative and qualitative detection of inorganic ions in the body fluid would be of inestimable value. The principle monovalent ions are hydrogen, sodium, chloride and bicarbonate; the main multivalent ones are magnesium, calcium and phosphate. Present techniques involve either delicate glass electrodes, flame photometry or awkward and tedious separation techniques.

Item: Analysis of Protein and Other Nitrogen Compounds

Particularly in the measurement of kidney function one needs to know the concentrations of urea, ammonia, and other nitrogen compounds in both tissues and fluids. With present techniques, analyses are very slow and often unspecific, Rapid and precise measurements are needed for these determinations as well as for the identification of enzymes and their many substrates.

Item: Respiratory Gas Analysis

Present pulmonary function tests require a certain amount of exertion, and are difficult to perform and record in order to obtain quantitative determinations of nitrogen, oxygen, carbon dioxide and anesthetic agents. Today, one might use techniques of infra-red absorption, magnetic effects and spectrographic analysis - surrounding the patient with racks of equipment. Continuous flow rate monitoring together with automatic sampling, analysis and recording, incorporating miniature single-breath analysis techniques could enable clinicians to examine pulmonary functions routinely.

In addition to better ways of analyzing total pulmonary performance, it must become possible to analyze vascular and gaseous diffusion of individual pulmonary lobules in order to conserve the maximum amount of functional tissue in lung surgery.

Item: Identification of Cells

Means of identifying congenital defects by microscopic examination of cell nuclei are needed. At the more fundamental research level further development of ultramicrochemical techniques for analysis of the chemical function of a single cell will make possible progress in the field of genetic transformation.

There are devices available today which automatically recognize and count the number of certain types of cells in a carefully mounted and stained specimen. Engineering advances needed include not only more sophistication in automatic discimination of cell types but greater ease in preparing the sample for automatic analysis.

Item: Identification of Organisms in Aerosols and Fluids

Culturing of material suspected to contain pathogenic bacteria is time consuming, and frequently the specification of the optimum treatment must be delayed until the bacteria have grown sufficiently to be visible. Some means of avoiding the prolonged period of culture is badly needed. Sophistication in the approach to identification (e. g. use of polarizing spectrometers for detection of asymmetric carbon atoms, etc.) and use of biological analog systems (an outgrowth of work in "bionics") are indicative of the engineering contribution needed.

4. Aids to Recognition of Physiological States and Patterns

The technology of automatic pattern recognition, and the sciences of underlying it are contributing now to such problems as language translation, and screening of cloud photographs. Application of this technology to automatic classification of x-ray images, and detection of cancerous cells will greatly facilitate public health service in disease detection.

In addition to automatic recognition of spatial patterns, there is a need for devices to identify abnormalities in temporal patterns of physiological data, making it possible for machines to truly assist the physician in identifying the ways in which a patient's state differs from health, and selecting the parameters which are, for a particular patient, the most important correlates of his present and probable future condition.

5. Tools for Research and Clinical Treatment

Item: More Precise Drug Treatment

A very necessary development is means of delivering definite amounts of antibiotics to sequestered sites, such as abscesses to avoid side effects of treatment. Perfusion techniques for treatment of cancer must be made more precise. Rapid, easy to administer, tests for determining an indivual's sensitivity to a given antiobiotic would expedite drug treatment.

Item: Equipment for Automatic Monitoring and Treatment

Continuous, automatic monitoring of physiological parameters has been discussed in several sections of this report, and the engineering advances needed in the various elements of such systems have been identified. Refinement of such equipment should make it possible to provide automatically certain simple services to patients, and control of fluid administration in post-operative complications and burn cases.

Bacterial filters for the protection of the patient during surgery are needed, and it would be highly desirable to provide(by electrostatic precipitation, ultraviolet radiation, etc.) large germ-free areas in every hospital for the protection of open-treatment burn patients, and patients whose natural mechansims of immunity have been rendered ineffective.

Tools to assist the surgeon in manipulating, stitching, etc. may reduce the time required for major operations, and thusly reduce the risk to the patient.

Item: New Materials

Certain properties of materials which are ordinarily of little or no concern to the engineer are of vital physiological importance; they include surface-wetting characteristics, inertness in the presence of organic and inorganic compounts, etc. Engineers and physicists have made, and are expected to continue making contributions to an understanding of clotting mechanisms and their control. Materials technology can be expected to provide improvements in the nature and variety of both the mundane materials of the surgeon - sutures and dressings - and the dramatic artificial equipment which the surgeon will be introducing to healing - synthetic valves, joints, piping, etc.

Item: Use of Novel Physical Phenomena

The physician has used heat and cold for treatment since medicine began. More recently he has employed the energies of electromagnetic radiation (x-rays, microwave, ultra violet, infra-red, laser, etc.) ultrasonic vibrations, high pressure and other media to affect the processes of living systems. Considerable attention has recently been given to "cryosurgery" - application of severe cold for the destruction or temporary suspension of physiological subsystem activity.

Engineering advances in control of the amount of energy imparted in location of the application and in monitoring the functional effect are needed in all of these areas.

In addition, the physical sciences and engineering must contribute to exploration of use of electrical and magnetic fields as therapeutic agents. One application of electrical energy which seems to have been further advanced in the USSR than in the West is its use in the place of drugs to induce unconsciousness.

6. Replacement Parts

One of the most exciting prospects of medicine is the replacement of diseased or otherwise inadequate parts of the body by artificial components or "borrowed" living parts. There is also the possibility of providing assistance (either temporary or permanent) to impaired physiological subsystems.

Representative of the more straight-forward contributions engineers can make to bring about these possibilities is the storage of large amounts and varieties of cadaver tissue, and the system to provide national (or international) inventory control, rapid access and delivery. There is more sophisticated engineering assistance needed in developing material components, and systems to facilitate replacement surgery. In providing artificial assistance to the kidney, for example, the capability of the kidney to remove toxin from the blood by dialysis must be replicated. Current artificial kidneys - which use synthetic membrane -

could be improved by the development of a material which could perform as a variable-mesh membrane, changing the dialysis progressively from the larger to the smaller particles.

Permanently implanted standby or supplementary devices have been proven practical in the case of cardiac activity control with the development of the artificial cardiac pacemaker. In terms of the goals cited earlier, the function of the pacemaker - providing precise electrical stimulation to the heart - seems modest enough, but the fact that a man-made system was designed to mimic a physiological function, and has successfully operated in patients' bodies for long periods, thereby permitting the pursuit of normal activities for long periods of time, is auspicious.

Largely under sponsorship of the Veterans Administration and the Vocational Rehabilitation Administration considerable attention has been given to development in the deaf, blind and crippled. There is an enormous amount of work yet to be done, for despite the efforts to date no substitute has been designed for normal sensory or motor performance. Prosthetic members have advanced furthest, but a satisfactory "hand" still eludes the engineer. Work in the area of prosthetics and sensory aids seems to have been characterized historically by "brute force approach" (which solved the problem of the less severely impaired), then a retreat to more basic study of the physical, physiological or psychological function to be replaced, and then a return to hardware attempts. Surgical repairparticularly in treatment of hearing and nervous control disorders - has progressed.

We are at a point, it seems, where the science and technology relevant to prosthetics and sensory aids have outstripped the ability of interested engineers to apply it.

E. General Needs of the Life Sciences and Medicine

In June 1963, the Department of Health, Education and Welfare, published a series of papers on "current and emerging issues" in areas of concern to the Department (95). The document identified the following among others, as topics* of great and growing concern:

Health
- Air and water
- Chronic conditions and disability
- Mental Retardation
- Hospital facilities and costs

Education
- Enrollment and attainment
- Library services

Welfare
- The aged

How can the space program contribute to solution of problems in these areas? The answer to this question must be given with respect to each problem. There are bound to be many activities underway in the next decade addressing these problems which will not reflect in any way the existence of the space effort.

*This list paraphrases the Department's list.

However we can state that if the will and the funds to apply space derived technology are available, the space program has demonstrated that technology exists, or is attainable to:

1. remotely observe and control virtually any characteristic of the physical environment.

2. transmit large amounts of data, and analyze these data automatically.

3. match men - machines and environment to achieve optimum (objectively measurable) performance.

4. simulate virtually any machine-bared task and environment.

Imanginative and sufficiently funded application of these abilities can have a profound effect upon health, education and welfare. In the meantime, it is expected that the present and growing technology of the space program will continue to improve the existing tools of life sciences and medicine (96) and contribute to their becoming more uniform in performance and more economical.

Equipment for automation of non-professional hospital function (house-keeping, record maintenance, environmental control, etc.) will greatly ease the administration's current cost crisis. Both number of personnel employed by hospitals and payroll have increased sharply in the last decade, with personnel up about 70% and payroll higher by nearly 300% (47a). The increase in annual payroll expense is considerably less than the net increases in assets of all hospitals (97), implying that, unlike most other technology-based "industries" hospitals have not invested heavily in automated equipment in recent years. Further indicative of this is the fact that while the number of doctors has increased at about the same rate as the general population in the past decade, and half-again as many registered nurses were [illegible] compared with 1950, sub-professional workers in virtually all categories more than doubled - contrary to the trend in virtually all other "industries" (98). It is the automating of the function performed by these sub-professionals that technology must be applied to if hospital costs are not to rise beyond reason.

Finally, the development of better instrumentation for bio-science research - relieving the life scientist from the "chores of equipping and administering with which he is singularly burdened - should make more productive manpower available for the creative aspects of basic research. In 1951, James B. Conant, viewing the impact of science upon industry and medicine, argued for more emphasis upon basic research whose findings are the "fuel" for the applied scientist (and the clinician and engineer) (99). Others (e.g. Stover, 100) urge the abandonment of those "present patterns (which) encourage the subordination of science to technology, and the exploitation of both", and recommends that the basic scientist be relieved of administrative burdens.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Summary of findings

How has the existence of the space program affected medicine, and what impact will space science and technology have upon life science research and practice? The preceding section presented a discussion of the nature and extent of the effect space activities have had and may have in the future. The transfer of space-derived science and technology into biomedicine has thus far been observed mainly in areas having problems similar to those of aerospace medicine. Thus the earliest significant instances of transfer of engineering innovations occurred in physiological monitoring. Similarly, hardware developed or refined to meet space medicine's need for detection of space cabin atmosphere constituents also meets clinical and research needs for environmental gas monitoring, and space-derived equipment is now marketed commercially.

Beyond these and other representative cases of hardware transfer, space medicine and biology is generating information and developing procedures which have already begun to be incorporated into non-space biomedicine. The problem involved in insuring that space crews survive and perform lengthy missions satisfactorily in an artificial, hazardous environment are stimulating research that will be applied, for example, to care of cardiac patients, assessment of "health", and preventive medicine in industry.

The space medicine effort is resulting in the development of facilities in contractor plants, NASA centers, and, eventually, in space, which might be used in the future to address problems of no immediate consequences to normal space flights. The effort devoted to the medical problems of man-in-space is producing a corps of engineers and physical scientists who are conversant with the language and solution constraints of medicine.

Then the activities of the space program that are termed "space medicine", "space biology", "biotechnology", etc. have already affected life science research and clinical practice. However, the portion of the space program devoted to life science problems is but a small part of the total program. What effect has there been on medicine of the vast expenditures for development of propulsion systems, vehicle structures, control and navigation devices, etc.? While the preceding section described a few cases, instances of life science exploitation of space system designs, materials, etc. have been rare. In fact, were there numerous instances of direct application to medicine of hardware designed to support space flight, one would be led to question the efficiency of space system engineering; the commonability of design criteria between life science equipment needs and the needs of space flight are few. This is not meant to discourage efforts to ferret out opportunities to utilize space technologies in the space program - indeed we recommend that activities of this kind be intensified - but it remains true that, apart from space medicine and biology, the space program will contribute more byproducts to the technologies of such industries as communications, transportation and electronics manufacturing than it will to biomedicine.

Although the catalog of space-dervied medical devices is not a large one, it will by no means describe the total effect of the space science and technology. The technical resources - personnel, facilities and management - now being directed toward exploration of space may be partially directed toward intensive attack upon biomedical problems. This is already happening in the case of several space contractors, who, with company funds, by and large, are addressing their engineering skills to such problems as hospital data processing, development of biological analogs, automatic analysis of electrocardiograms, automobile accident prevention, etc.

Exchange of information between space scientists and life scientists outside of the space program must take place through the existing channels of communication used by life scientists. Innovations resulting from space program activities must compete for the scientist's attention with the growing number of new ideas being generated within the life sciences. If NASA is to expedite the transfer of science technology the agency must take into account the differences in information-seeking habits of the various specialties. In fields such as genetics and artificial organs, for example, the pace of research requires that the scientist rely heavily upon information communication. Along another dimension -

extending from basic research to clinical research - the information requirement varies from detail information about relatively few subjects to less detailed information about a great number of subjects.

Perhaps the greatest barrier to utilization by the life sciences of the resevoir of science and technology generated under the space program is the problem of "translation" of physical science and engineering information into terms which are meaningful to life scientists. However, the number of physical scientists and engineers engaged in life science research programs is growing, many medical and engineering shools during the past five years have established formal or informal cross-training programs for engineers and physicians, and new interdisciplinary journals have been established to facilitate communication among those whose work bridges the life sciences and physical sciences.

The shortage of physical science - life science interpreters is not the only deterrant to rapid adoption of space-derived innovations in fields related to medicine. The following are other conditions of the "market" which must be modified, or taken into account in attempting to accelerate the flow of physical science and engineering ideas from the space program into medical research and practice.

The extraordinary complexity of the subject matter of biomedicine (living systems) makes it difficult to evaluate the usefulness of new or refined means of study and treatment. If the technical value of a new biomedical tool is hard to determine, the economic value of medical diagnostic or treatment equipment often simply cannot be determined. The uncertainty attending innovation acceptance decisions in the life science tends to delay and impede adoption of change - though the increase of federal support for medical research and clinical facilities in recent years appears to have increased willingness to take risks in investment of time and funds for innovations.

It appears to be more difficult for hospital administrators to allocate capital and operating funds for hardware innovations than for personnel costs.

Because of the shortage of engineers and engineering technicians in medical fields, and the relatively small number of life scientists trained in engineering, equipment must be (expensively) reliable and straight-forward in operation.

Because NASA is primarily a mission-oriented agency, only a small portion of the efforts of its own and contractor personnel is devoted to exploring ways of applying space science and technology to medical innovation needs. It is left to the life science community, and to the manufacturers serving it to match the needs with available space technology. As indicated earlier the demand for change - new or markedly improved products and services - is not yet large enough to stimulate sizeable private investment in application and transformation of advanced technology.

The transfer of space technology into biomedical specialties is proceding at a modest though accelerating rate. In general, life scientists are dependent on industrial firms for the application of aerospace innovations to improved techniques useful in non-aerospace biomedical areas now most often reaches user scientists only after lengthy delays, if at all. Improved communications will help this transfer, but the effects of recent improvements and those now planned or recommended in the preceding section will require considerable time before significantly changing this situation. Active measures even of a temporary nature, should be taken to promote adoption of aerospace program innovations and exploitation of new knowledge gained from this program.

B. Recommendations

This report has summarized our findings regarding the effect the space program has had, and can have upon medicine. Reviewing the habits of life scientists with respect to acquisition of information from other disciplines, and patterns of innovation acceptance, we have identified the kinds of contributions the results of space scientific and technological efforts can make. A certain amount of technological transfers will occur whether or not there exists a formal NASA program designed to effect transfers, but we believe the life science community would greatly benefit if NASA continues and expands its effort to facilitate transfer of information. In a sense, promoting the use of space-derived science and technology is a marketing problem.

Within this conceptual framework, clearly the primary lack of the producer and seller - NASA - to define its product line: a continuing assessment of what it is that it has to "sell" to the life scientist. Thus managers of NASA and representatives of life science community interests must together take stock of the body of knowledge being generated under the space program.

We believe that this can best be done by identifying needs and areas of need which exists in medicine - such as those outlined in Section V, and at the same time "search" the NASA information inventory for scientific material (data, theory, methodology, etc.) and technology (problem-solving techniques) which is relevant to those needs. Initially it seems that a modest effort along the following lines would be useful, and its performance would yield an indication of the cost/effectiveness tradeoffs in efforts of this type.

Identification of Needs for Innovations in Life Sciences

The first step would be to identify and solicit the cooperation of individuals having interest in space program - life science communication. Representative of persons who are familiar with the needs for innovation in the life sciences are:

1. Individuals having demonstrated unusual inventiveness in research or clinical practice (could be identified by officers of the approximately twenty major life science professional societies).

2. Professional managers of formal communication within the life sciences
   a. Editors of journals
   b. Director of abstracting and information exchange service
   c. Marketing executives of drug firms, medical apparatus companies and basic materials manufacturers (plastics, metals, etc.).

3. New-products managers
   a. Space contractors which have developed an in-house life science capability
   b. Medical equipment firms

4. Federal and private sponsors of advances in medical research and practice.

5. Educators
   a. Medical school and life science department heads
   b. Professional society education committee chairman, annual convention program chairman

6. Specialists in physical science and engineering utilization in medicine
   a. Bio-physicists and bio-mathematicians
   b. Medical engineers

7. Participants in the transfer of space science and technology to medicine which has occurred thus far
   a. Space medicine specialists
   b. Consultants to the space medicine and technology utilization programs of NASA, the Air Force and the Navy.

Having identified - though not necessarily contacted - roughly one hundred individuals who could contribute to compilation of a representative list of needed innovations, NASA-OTU might then establish a framework within which the needs are to be described. Such a framework might be of the following type:

Life Science Professional Specialty

	Specialty a		Specialty n
	Problem a-1	Problem a-2	
	Context: Significance: Constraints or solutions: Inadequacy of what is now available: Known current and recent efforts to solve this problem:		
Data Acquisition			
Data Transmission			
Display, or Storage			
Data Analysis			
Means of Physical or Chemical Interventions			
Materials			
Theory to Fit Observed Phenomena			
Experimental Methodology (Design or Procedure)			
Operational Techniques to Reduce Cost or Increase Effectiveness			
Planning Techniques			

The actual solicitation of problem statements could be by correspondence or meeting or some combination. It will be important to inform those cooperating of the need for specificity in statement of problems.

Problem statements might then be given an initial screening to eliminate from further considerations those problems which are too trivial or too intractable. Also to be set aside are problems for which a solution is likely to be readily provided by industrial products or services or result from present or programmed research elsewhere. The remaining problems would probably need some refinement in specification.

Identification of Available Relevant Space Science and Technology

The matching half of this effort to "inventory" the knowledge that the space program can contribute to the life sciences is to review space program activities. There are within NASA a number of physicians, physiologists, psychologists, bio-engineers and others who are familiar with various aspects of the space program, and are also familiar with innovation needs of life sciences. With their assistance, and the cooperation of major program management personnel, the next step would be to make a first pass at identifying projects - or areas of work - which appear to be closely related to needs of medicine and its supporting sciences. The product of this review effort would be a catalog of projects having elements (e.g. sensing, or display, etc.) analagous to those identified in the innovation-need statements.

We recognize that such an orderly approach will achieve "matching" of more than a fraction of needs - available technology situations which exist. There will be many opportunities missed, and probably a number of "false alarms" - matches of needs to technology which simply cannot be made because of economics or other considerations.

Development of a Program to Disseminate the Items of Possible Transfer Which Have Been Identified

Once there has been identified the "inventory" of available relevant technology, there remains the problem of promoting the use of this information in the life sciences. The purpose of this dissemination effort would be to inform potential application and user groups of the availability of the knowledge, to stimulate the interest of life scientists and individuals in the space program as a source of new ideas, and, finally, to assist in educating the life science community as to what kinds of technology are available - to lower their resistance to innovations.

Before designing the program of activities to effect dissemination, NASA-OTU must decide several significant policy questions. Among them are:

1. What proportion of the space program, funds and human resources are to be devoted to assisting the transfer of technology to medicine and to allied sciences?

2. What criteria are to be used in deciding upon the emphasis to be given to transfer of various kinds of potential transfer? For example, how should the emphasis be divided between trying to assist flow of ideas to public health clinicians or basic researchers?

3. What measures are to be used in monitoring the effectiveness of technology transfer efforts?

4. What strategy should be used in designing the technology transfer assistance program? The following represent alternative broad strategies which must be defined and evaluated:

   a. Minimize time lag between recognition and specification of need and transfer of technology.

   b. Maximize number of individuals who will receive some exposure to instances of technology transfer.

   c. Concentrate upon effecting the transfer of some item - in the extreme providing production and marketing assistance to manufacturers which can serve as cases.

   d. Condition the life science community to looking to space science and technology for approaches to solution of their problem.

We recommend that NASA solicit the view of its own technical personnel and life science community leaders such as those described above in the course of considering such alternative strategies. After the policy objectives and general strategy of the transfer-of-technology-in-medicine program have been decided upon there remains the task of designing the program, and establishing the administrative mechanisms for operating and monitoring it.

Program Design Considerations

1. It appears to us to be vital that NASA coordinate with other agencies its efforts to facilitate the transfer of technology into medicine.

a. Having primary federal responsibility for the health of the nation, the Department of Health, Education and Welfare is charged with being aware of present and future needs for improvement of knowledge and means of applying it. The Department has efforts underway to facilitate the flow of ideas from its own research program to the life science community, and there are many areas in which NASA and DHEW may collaborate.

b. Representative of the ways in which NASA and Department of Defense can collaborate in accelerating the dissemination of space science and technology is the possibility of working through the existing Medical Education for National Defense program of DoD. The MEND program employs medical school staff personnel on a part time basis to make reports of military-supported life science research available to medical students and faculty. In addition, the program - relatively modest in scale - provides medical school libraries with subscriptions to such journals as Aerospace Medicine, Military Medicine, etc., and arranges symposia.

The Defense Department has another program which is related to NASA's interest in technology utilization - planning the diversion of military contractor capability to non-armaments activities.

2. NASA encourages its professional personnel to participate in the activities of their professional societies. In addition to msintaining this policy, the agency might consider the following:

a. Encouraging - or requiring - that students who hold NASA life-science fellowships become acquainted with space program activities relevant to their professional interests.

b. Expand efforts in joint sponsorship of biological and behavioral science symposia.

3. Increase the motivation of individuals in NASA centers and contractor facilities to identify opportunities for transfer.

An activity is self-motivating to an individual when its pursuit leads him toward personal growth, and/or satisfaction from working with a "good" group, and/or achievement of stated goals of the organization. Because a mission oriented center, or a profit oriented contractor cannot be expected to place a high value on the efforts of its employees to identify opportunities for technology transfer to medicine, personal satisfaction and social and financial rewards for such effort may in some situations be best provided by OTU outside the line organization.

4. The Aerospace Research Application Center concept developed at Indiana University may be applicable to scientific and technological transfer in the life science context, and the Center's experience in defining the space program's activities relevant to a subscriber's interest would be particularly valuable in planning dissemination of innovation information to life scientists.

5. Management of information dissemination activities.

The analytic methods presented by Rogers (24) and other students of diffusion of innovations can be a great aid in designing and operating the efforts of NASA to facilitate the use of its technology in medicine. Rogers conceives of the processes involved in adoption of new ideas as. generation of the innovation, and communication about it occuring within a social (or economic) system, over a period of time. During this period of time potential users of the innovation may become aware of it, may try it and adopt or reject it. There are in theory, optimum activities that the "transfer agent" (here, NASA-OTU) can select at each point in the diffusion process. Refining the conceptual descriptions of Rogers, and observing the advice of such students as Quinn and Mueller ("identify and examine resistance at critical technological transfer points") should produce a format for each part of NASA's plan for facilitating transfer.

Management of the flow of information from the space program to the life sciences could benefit from use of PERT techniques to plan and monitor efforts.

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APPENDIX

NASA QUESTIONNAIRE

A twenty-two item questionnaire was used to obtain information on the exchange methods used by NASA supported researchers. Of the 58 questionnaires sent out, 36 were returned (about 62 percent of the total), although three of these were returned blank. The recipients of these questionnaires were engaged in research in the life sciences (medicine, biology, physiology, etc.), and were selected from the NASA grants and contracts list (Grants and Research Contracts, Office of Grants and Research Contracts, NASA, Washington 25, D.C., July, 1963.). Questionnaire recipients' grants or contracts may be subdivided into three categories: first, those that have been completed; second, those that are still in progress; and third, those that have been recently awarded. Figure 1 shows the distribution among these categories and the duration of NASA grants and contracts of those individuals who returned the completed questionnaires.

Questions

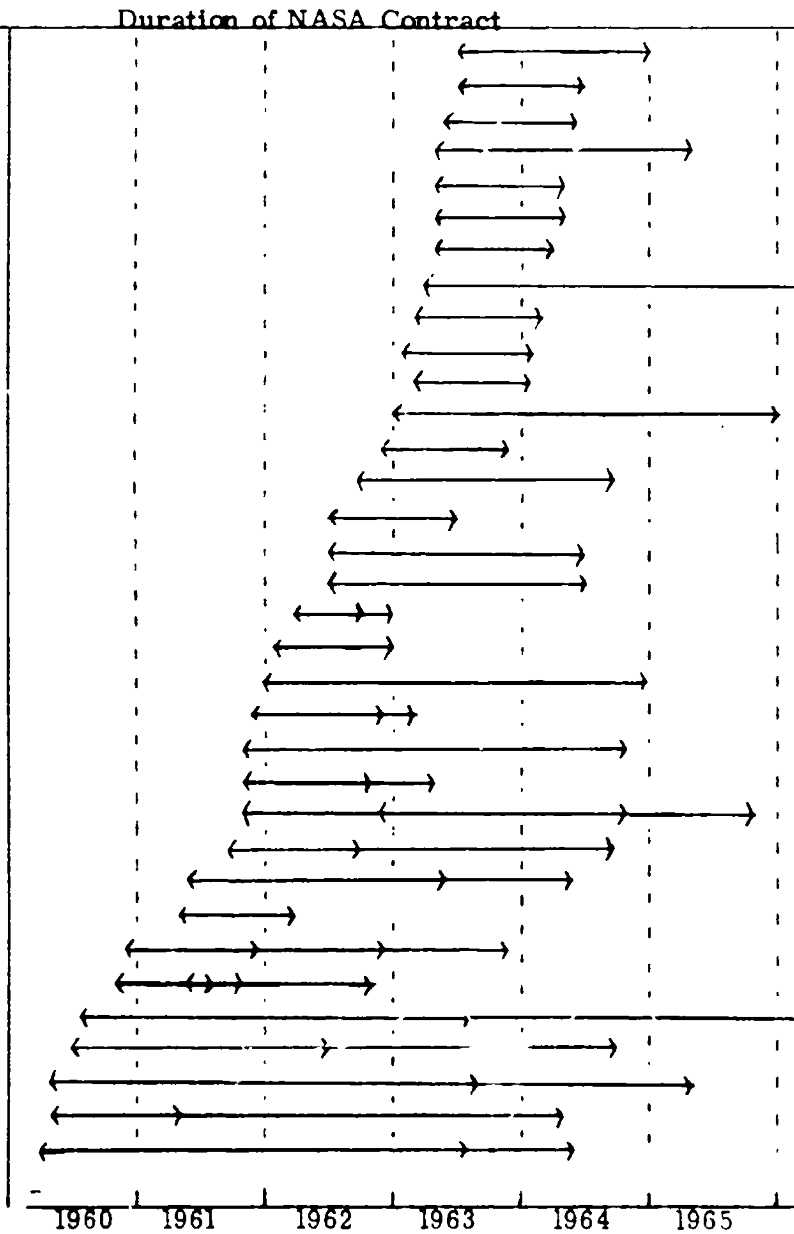
1. At how many domestic scientific meetings have your NASA sponsored research results been presented?

2. At how many foreign scientific meetings have your NASA sponsored research results been presented?

3. At how many specialized conferences and symposia have your NASA sponsored research results been presented?

Figure 1

Code	Contract Dates	Months	Tech. Pub.*
34	6/63-12/64	18	
58	6/63-6/64	12	
29	5/63-5/64	12	
18	4/63-4/65	24	
13	4/63-4/64	12	
11	4/63-4/64	12	
45	4/63-3/64	12	
27	3/63-3/66	36	
14	2/63-2/64	12	2
3	1/63-1/64	12	
37	2/63-1/64	12	1
12	12/62-12/65	36	
46	11/62-11/63	12	
55	9/62-9/64	24	1
33	6/62-6/63	12	1
59	6/62-6/64	24	3
2	6/62-6/64	24	
49	3/62-12/62	9	
1	1/62-12/62	12	
41	12/61-12/64	36	
57	11/61-2/63	16	
56	10/61-10/64	36	
4	10/61-4/63	18	1
62	10/61-10/65	48	2
15	9/61-9/64	36	2
25	5/61-5/64	36	1
60	4/61-3/62	11	
21	11/60-11/63	36	
47	10/60-10/62	24	2
30	7/60-7/66	72	7
32	6/60-9/64	51	4
28	4/60-4/65	60	14
53	4/60-4/64	48	1
7	3/60-5/64	50	2



* Technical Publications

Answers to these questions are summarized in Figure 2. The duration over which the contract has been in effect must be considered in interpreting the significance of the individual responses. The results are in two forms: first, the meetings attended are given for each respondee; second, the totals are given for each type of meeting attended - domestic, (90), foreign (14), special (36).

4. Are financial arrangements with NASA adequate for attendance at sufficient foreign and domestic meetings?

The responses are as follows:

domestic meetings	23 yes (adequate financial arrangements) 7 no 2 no funds requested 1 unanswered
foreign meetings	5 yes 20 no 2 no funds requested 6 unanswered

5. In how many books have the results of your NASA sponsored research appeared?

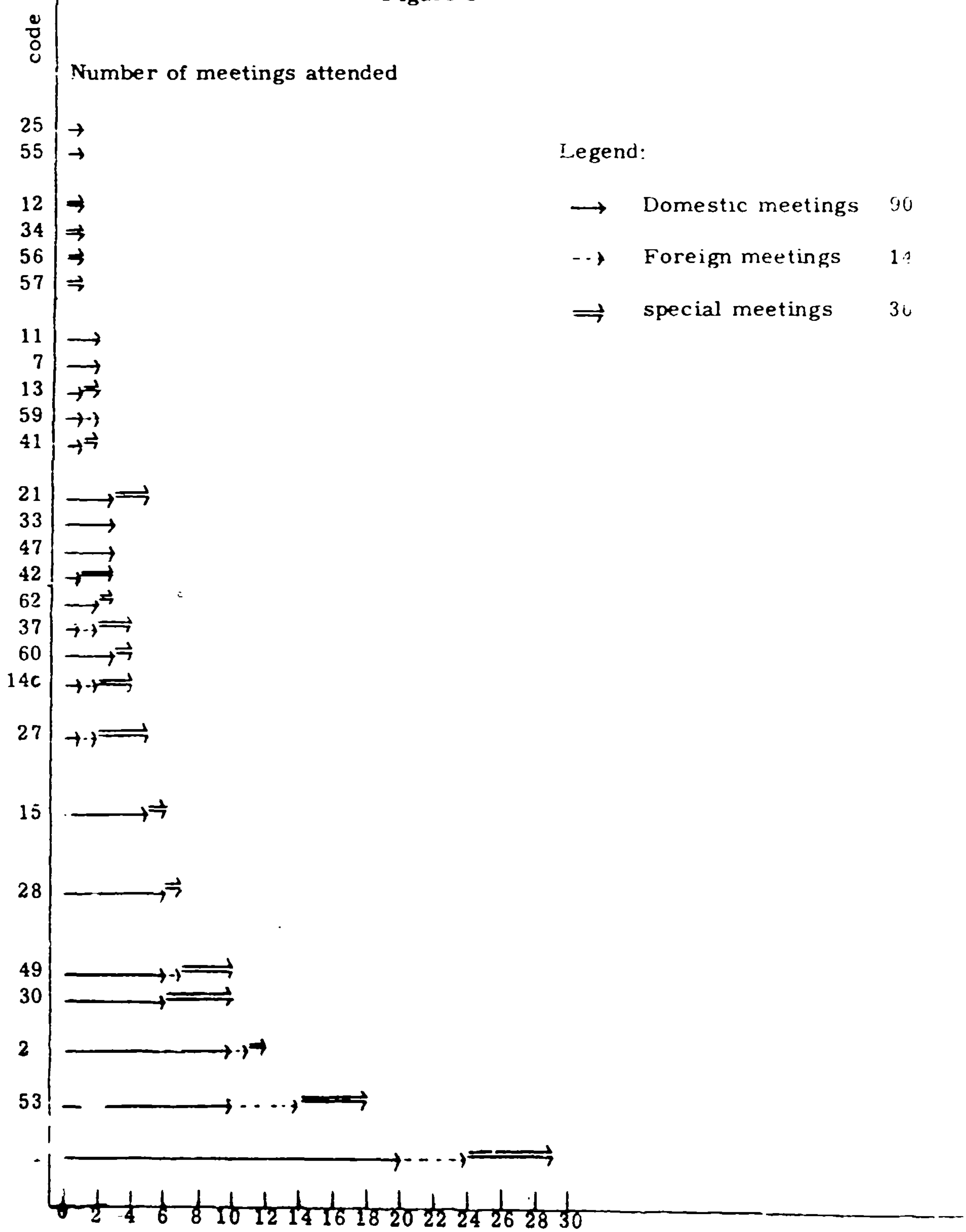
   25 none of NASA sponsored research appeared in books
   6 NASA sponsored research appeared in books
   2 NASA sponsored research is in preparation for books

6. In what commercial publications (e.g. magazines, newspapers, in house publications, etc.) have results of your NASA sponsored research appeared?

   23 none of NASA sponsored research results appeared in commercial publications.

   7 NASA sponsored research results appeared in the following commercial publications:

Figure 2


code
Number of meetings attended
25
55
12
34
56
57
11
7
13
59
41
21
33
47
42
62
37
60
14c
27
15
28
49
30
2
53
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Legend:
Domestic meetings 90
Foreign meetings 14
special meetings

Time	Medical Newsweek
Newsweek	GE Newspaper (plant)
Aviation Week	Bioastronautics
Missiles & Rockets	Science Service
Local Newspapers	University of Arizona Publication
AP release	Medical World News

2 NASA sponsored research results in commercial publications. but sources of publications are vague. One respondee said that his research results appeared in many commercial publications; another gave 20-30 publications.

1 NASA sponsored research results are in preparation for publishing in commercial literature.

7. In what scientific journals? (have your NASA sponsored research appeared).

7 NASA sponsored research has not appeared anywhere (no explanation given).

4 NASA sponsored research has not appeared anywhere - support has started only recently.

1 NASA sponsored research has not appeared anywhere - project not completed.

2 NASA sponsored research results are in preparation for publication.

1 NASA sponsored research results are in press as of the time of answering the questionnaire.

17 NASA sponsored research results appeared in the following scientific journals:

Aerospace Medicine 2
American Journal of Botany
American Journal of Pathology
American Rocket Society Journal

Biochemica et Biophysica Acta

Circulation
Crop Science

EEG Journal
Experientia
Experimental Cell Research
Experimental Neurology

Federal Proceedings

Industrial and Engineering Chemistry

Journal of the American Institute of Chemical Engineering
Journal of Cell Biology
Journal of Experimental Botany
Journal of Molecular Biology

Nature
Neurology

Perceptual and Motor Skills ?
Plant & Cell Physiology
Plant Physiology
Proceedings of the National Academy of Science
Proceedings of the Oklahoma Academy of Science
Proceedings of the 16th Annual Conference on Engineering in Medicine and Biology

Review of Scientific Instruments

Science 4

Transactions of the Finnish Academy of Science
Transactions, Society Rheology

6. Would you please indicate the title, reference, and es timated number of reprint requests of your paper published in open literature under NASA sponsorship (Include domestic and foreign scientific journals).

18 NASA supported research results have not been published in the open scientific literature.

1 Answered incompletely - 20 papers and 500 reprints per paper.

15 gave references of the publications, which are listed below using the names of respondees as the principal authors (some of these references have not been checked against the publications and inevitably some names of co-authors have been excluded - we apologize for this omission).

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Black-Schaffer, B., Hensley, G. T., and Simon, L. R., Protection of the Adult Mouse Against 1800 G Acceleration by Hypothermic Immersion, Aerospace Med., 32:119-1126, 1961. 30 reprints.

Black-Schaffer, B., Protection by Deep Hypothermia and Immersion Against 2300 G Acceleration of a Non-Hibernator (rat) and Hibernator (hamster) Aerospace Med., 33:286-289, 1962. 50 reprints.

Cooper, O. L., A Miniaturized 15-Channel Telemetry Transmitter for Upper Atmosphere Research, Proc. Okla. Acad. Sci. 42, 1962. 5 Reprints.
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Marmur, J., and Greenspan, G., Transcription in vivo of DNA from bacteriophage SP 8, Science, 142:387, 1963. 500 reprints.

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Kenshalo, D., Improved Method for the Psychophysical Study of the Temperature Sense, Rev. Sci. Insti, 34:883-886, 1963, 7 reprints.

Kenshalo, D., and Nafe, J., Cutaneous Vascular Systems as a Model Temperature Receptor, Percept. & Motor Skills, 17:257-258, 1963, 7 reprints.

Lederberg, J., Microenvironments for Life on Mars, Proc. Nat. Acad. Sci., 48:1473-1475, 1963. 125 reprints.

Lyon, C. V., Auxin Transport in Leaf Epinasty, Plant Physiol. 38:567-574, 1963. 50 reprints.

Musacchia, X. J., and Neff, S. S., Absorption of D-Glucose by Segments of Intestine from Active and Hibernating, Irradiated and Non-Irradiated Ground Squirrels, Citellus Tridecemlineatus, Manuscript Submitted to Trans. Finn. Acad. Sci., 1963. 50 reprints.

Musacchia, X. J., Active Absorption of D-Glucose by Intestinal Segments of the Ground Squirrel, manuscript submitted to J. Comp. Biochem. and Physiol.

Mussacchia, X. J., Cooper, T., and Jellinek, M., Effects of X-Irradiation during Hibernation on Tissue Catecholamine Contents, Manuscript Submitted to Experientia, 1964, 150 reprints.

Plasek, D. V., An Instrument for Measuring Torsional Creep and Recovery, Trans. Soc. Rheol. 7:61-74, 1963. 6 reprints.

Proctor, L. D., A Computer Identification of the EEG in a Neurophysiological-Behavioral Problem, Proc. 5th IBM Med. Symposium. 200 reprints.

Sorokin, C., and Krauss, R. W., Relative Efficiency of Photosynthesis in the Course of Cell Development, Biochem. Biophys. Acta, 48:314-319, 1961. 450 reprints.

Sorokin, E., Effects of Illuminance Near and Below Light Saturation on the Time Course of Photosynthesis in Synchronized Cultures of Algae, J. Exp. Bot., 12:56-64, 1961. 450 reprints.

-------Time Course of Oxygen Evolution During Photosynthesis in Synchronized Cultures of Algae, Plant. Physiol. 36 (2):232-239, 1961. 250 reprints.

-------Time Course of Photosynthesis in Bi-carbonate Buffer in Synchronized Cultures of Algae, Arch. Mikrobiol., 40:418-429, 1961, 200 reprints.

-------and Krauss, R. W., Effects of Temperature and Illuminance on Chlorella Growth Uncoupled From Cell Division, Plant Physiol., 37(1): 37-42, 1962. 300 reprints.

-------Inhibition of Cell Division by Carbon Dioxide, Nature (London) 194(4827):496-497, 1962, 450 reprints.

-------Effects of Acidity on Cell Division, Exp. Cell Res., 27:583-584, 1962. 450 Reprints.

-------Carbon Dioxide and Bicarbonate in Cell Division, Arch. Mikrobiol. 44:219-227, 1962. 450 reprints.

-------Injury and Recovery of Photosynthesis in Cells of Successive Developmental Stages: Temperature Effects, Plant and Cell Physiol. Special Issue. Studies on Microalgae and Photosynthetic Bacteria, pp. 99-109, 1963. 300 Reprints.

-------Characteristics of the Process of Aging in Algae Cells, (Abstract), Science, April 26, 1963, 150 Reprints.

-------The Capacity for Organic Synthesis in Cells of Successive Developmental Stages, Arch. Microbiol., 46:29-43, 1963.

-------Buffering Activity of Algae Cells and Its Effect on Cell Division, Exp. Cell Res., in press.

-------On the Variability in the Activity of the Photosynthetic Mechanisms, Submitted for Publication. Symposium on Photosynthetic Mechanisms.

-------and Krauss, R. W., The Dependence of Cell Division in Chlorella On Temperature and Light Intensity, Accepted for Publication in American Journal of Botany.

Lancaster, J. H., Tischer, R. G., and Long, R. J., Human Feces as a Nitrogen Source for Some Green Algae, Dev. in Industr. Mircobiol., Vol. 3 (New York), Plenum Press. 1961.

Cody, R. M., and Tischer, R. G. Microbial Synthesis of Animal Feeds from Human Waste Substrates, Reprinted from Dev. In Industr. Microbiol. Vol. 3. (New York), Plenum Press, 1962.

Tischer, R. G., Tischer, B. P., and Cook, D. W., Human Feces as a Nutrient for Algae in Closed Space Ecologies, Dev. In Industr. Microbiol., Vol. 3 (New York), Plenum Press, 1962.

----and----, Open Sequence Components of a Closed Ecology, Amer. Biol. Teacher, 25 (6): 444-449, Oct. 1963. 60 reprints in 40 days.

Cody, R. M. and Tischer, R. G., Quantitative Measurement of Urinary Nitrogen and Total Solids Depletion in a Closed Ecological System during Microbial Synthesis, Dev. In Industr. Microbiol., 4:261-267, 1963. 35 Reprints in 40 days.

Tsuchiya, H. M., Continuous Propagation of Micro-organisms, A. I. Ch. E. J., 9:459, 1963. 30 reprints.

-------, Mass Transfer Characteristics of a Venturi Liquid-Gas Contactors, I. E. C. Proc. Design and Dev., 2:178, 1963. 50 reprints.

-------, Opt. Conditions for Photosynthesis in Opt. Dense Cultures of Algae, A. R. S. J., p. 1429, Oct. 1961. 20 reprints.

Waggoner, P. E., Optimum Lighting of Leaves, Crop Science (in press), 200 reprints.

Ziemnowicz, S. A. R., Technics of Regional Rheography for Monitoring the Circulation in the Brain and in the Eye, Proc. 16th Ann. Conf. Engin. Med & Biol., Nov. 1963. 34 reprints.

The following papers were presented at various symposia. It is not clear whether or not the proceedings of these symposia have been published.

Helvey, W. M. The Effects of Prolonged Exposure to Pure O_2 on human Performance, 34th Meeting of Aerospace Medical Association, 1963. 25 reprints.

Kenshalo, D., and Nafe, J., The Operation of the Tactile and Temperature Senses, (invited paper), Symposium of the Physiological-Psychological Branch of the Office of Naval Research, March 1962. 7 reprints.

Marmur, et al, Cold Spring Harbor Symposium on Quantitative Biology, Dec., 1963.

Tischer, R. G., Tischer, B. P., Brown, L. R., and Michelson, J. C., Electrolytic Treatment of Human Wastes for Use in Closed Ecologies, Miss. State Univ. College, Miss. Presented at AIBS meeting in Cornwallis, Ore., 1962.

Nine of the respondees gave either the number of requested reprints or the percentage of requests from different disciplines, but not both. It was impossible to include their responses into Table I.

The remaining 14 gave no answer to the number of reprint requests nor to the disciplines to which the reprints were distributed.

9. Of the total number of requests for reprints received it is possible to estimate the number which originated in specific disciplines, e.g. chemistry, physics, biology, etc. Only 10 questionnaires could be used to pool answers for this request. The pooling was done in the following manner: the percentage of reprints in a given field was converted into a number of reprints. Then, the number of reprints was added for each discipline and the percentage of the total obtained. Table I shows the summary of results.

TABLE I

Summary of results showing the discipline of those who requested reprints from 9 research scientists supported by NASA.

Discipline	Reprints	Percentage
Biology	4021	84

Discipline	Reprints	Percentage
Medicine	243	<5
Medicine & Biology	225	<5
Chemistry	175	4
Engineering	70	>1
Physics	24	<1
Physiology	21	<1
Total	4779	100

10. What is the estimate of the average time lag between submission of a paper and publication?

    The answers to this question are summarized in Figure 3.

11. Outside of formal methods of scientific communications mentioned, what techniques of scientific information dissemination do you consider important?

12. Do you consider these additional techniques more important or less important than the formal techniques listed?

    Table II gives a summary of additional techniques and their importance. Some respondees gave two or more additional techniques; therefore, the frequency of responses is greater than the number of completed questionnaires.

13. Do you apply other NASA or USAF research development (theories or techniques) to your own research? (Could you give brief examples?)

    The answers to this question were as follows:

Figure 3

Time Lag Between Submission of a Manuscript and Publication

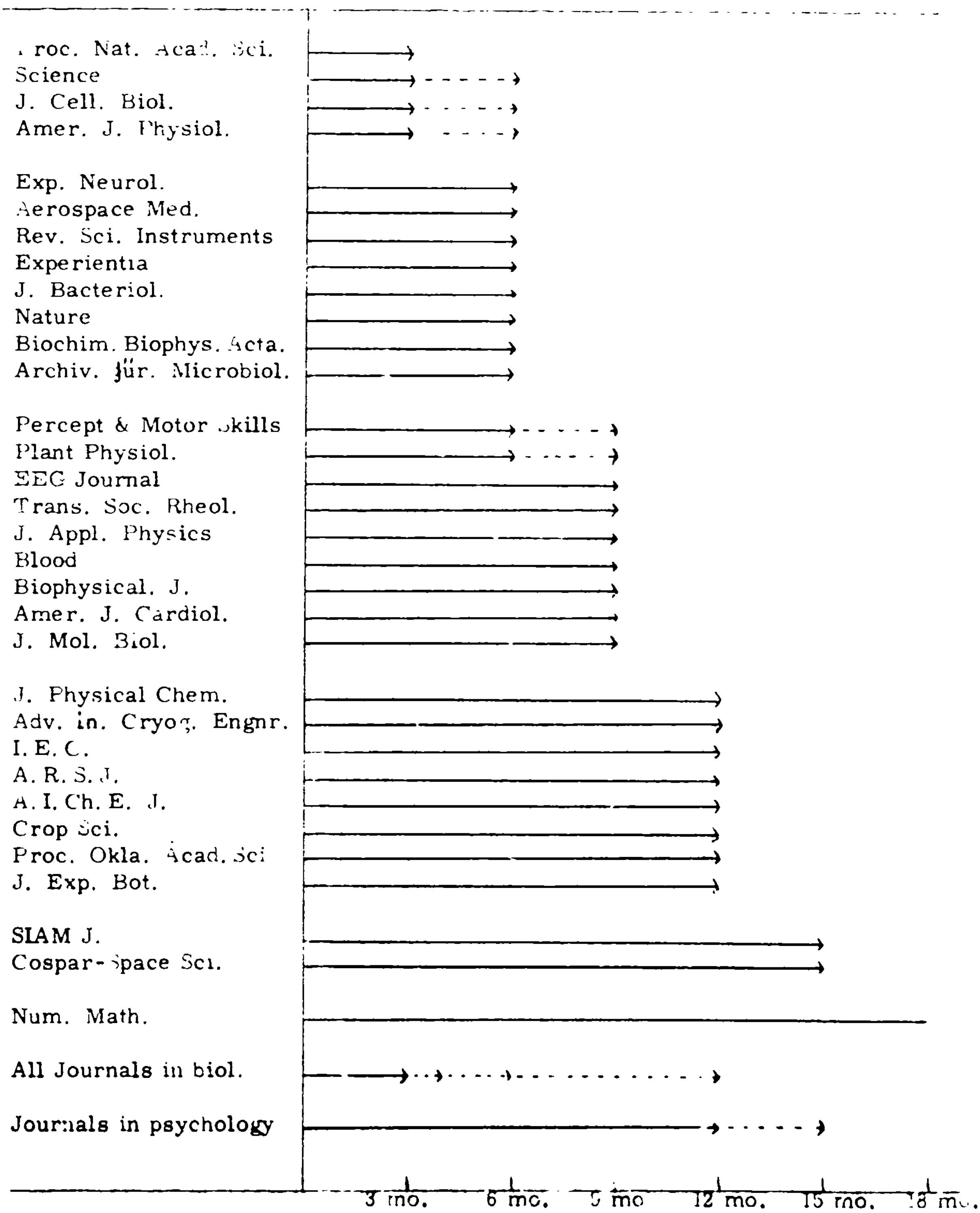


TABLE II

Summary of results given to questions 10 and 11 - frequency of responses.

Formal methods of scientific communication:

Domestic scientific meetings and committees
Foreign scientific meetings and committees
Specialized conferences, symposia and congresses
Research results appearing in books
Research results appearing in commercial publications
Research results appearing in scientific periodicals.

Additional techniques for dissemination of scientific information:

Technique	Less Important	Depends	Equal	More Important
Scientific Meetings			1	
Congresses		1		
Literature			4	1
Committees			1	
Symposia			1	1
Visits to labs	1	1	3	1
Personal meetings	3	1	9	1
Discussion	1		2	1
Correspondence	2		4	1
Speakers			1	
Reprints (exchange of lit)			1	1
Telephone	1		1	1
Informal Symposia	1			
	9	2*	21*	6*

*Excluding the more formal techniques

10 yes - NASA or USAF research development is applied to respondee's own research.

15 no - NASA or USAF research development is not applied to respondee's own research.

1 limited.

1 Lovelace Foundation

6 did not answer this question.

14. Did the essential idea or technique used in your research effort originate specifically from space program information?

15. If answer to above is yes, could you give specific instances of origin? (e.g. journal, report, etc.)

Most of the answers (28) to question 14 were negative; then question 15 was not applicable.

Two respondees did not answer questions 14 and 15.

Four respondees who answered question 14 affirmatively gave the following explanations to question 15:

1. Answer to question 14 - some ideas did so originate.
   Answer to question 15 - conversation with a member of one of the scientific committees, as well as my own participation on another committee.

2. Answer to question 14 - ideas from space program problems.
   Answer to question 15 - knowledge of problem not specific, i.e., journals and reports.

3. Answer to question 14 - originated from AEC, AF, NASA, and articles in many magazines.
   Answer to question 15 - A recent example -- articles by Fowles, Curran of Stanford Research Institute, in Journal of Applied Physics. Also wrote directly to Fowles.

16. Is the intent of your research effort directed specifically to the space program or do you feel the results will have general application in your academic discipline?

17. In what areas do you feel the research results would have use?

    The answers to these two questions are summarized in the following list:

Research efforts directed specifically to the space program.

Five grantees were doing work in the following areas:

solid state
superconductivity
space research
cellular replication
behavioral sciences.

Research efforts will have general application in investigators' academic discipline.

Four grantees felt that application would be in the following academic areas:

1. physical sciences
   astrophysics
   metallurgy
   ultraminiaturization
   electron optical technology

2. life sciences
   biochemistry
   biomedical research
   microbiology
   cell biology
   molecular biology
   biophysics

   psychology-perception

Eight respondees felt that results obtained from NASA sponsored research would have applications in both the space program and in their (respondees) own academic disciplines. The following areas of application of results were listed:

1. Space applications

   space travel
   uses of radiant energy
   waste treatment
   automation in processing biomedical data
   life support-use of leafy plants to recycle O_2 and CO_2
   selection.

2. Medical sciences

   medical science
   surgery
   cardiology
   infectious diseases

3. Research areas

   cell physiology
   cell division
   basic mechanisms of cellular functions
   aging
   photosynthesis
   propagation of micro-organisms
   evaluation of biological age

One respondee felt that results obtained from NASA sponsored research would have industrial applications.

Fifteen respondees felt that results of NASA sponsored research would have general application. Areas in which research results would be applied are as follows:

1. Physical Sciences

astronomy
computer science
computer simulation
chemical physics
applied mathematics
chemical engineering
design and process of polymer articles

2. Medical Sciences

medicine
clinical medicine
clinical cardiology
clinical ENT
hematology

3. Biology, Physiology, Anatomy

biology
molecular biology
microbiology
physiology
plant physiology
cardiopulmonary physiology

neuroanatomy

sensory systems

4. Research Areas

experimental medicine
medical research
biological research
genetics

5. Pharmacology

pharmaceuticals
neuropharmacology
food

6. Other

agriculture
biodynamics
space application
aeromedical and space projects

18. With how many colleagues in your institution do you discuss your work? ____________. How many hours per week? ______ ______.

The answers to this question are given in Table III.

TABLE III

Summary of responses to question 18.

Respondees	Number of Colleagues	Respondees	Numbers of hours per week
2	2	1	1/4
5	3	4	1
8	4	7	2
2	5	1	3
2	6	3	4 *
3	7	4	5
1	9	2	6
3	10	1	7
2	11	1	10
2	12	1	15
1	20	1	20
1	30	1	30
		1	40
		5	no response

19. Have these colleagues contributed sources of information with which you were unfamiliar and which contributed to your research?

    yes____ no____.

    The majority of respondees (28) felt that their colleagues contributed new information. However, one respondee felt that the contribution of his colleagues was only slight; another felt that such contribution occurred seldomly.

    Only three respondees felt that their colleagues did not contribute any new information.

20. How often during the past year have you traveled to other institutions to discuss informally with colleagues your mutual work?

    The responses to this question are grouped in the following manner.

*median for those responding

Respondees	No. of Visits
4	0
4	1
9	2
1	3 *
1	4
1	5
6	6
1	7
1	9
2	12
2	15
2	no response

21. How would you describe your library facility?
    (Circle appropriate description) poor - fair - adequate - good - excellent

    Responses to this question are as follows:

excellent	-	13
good	-	9
adequate	-	6
fair	-	4
poor	-	0

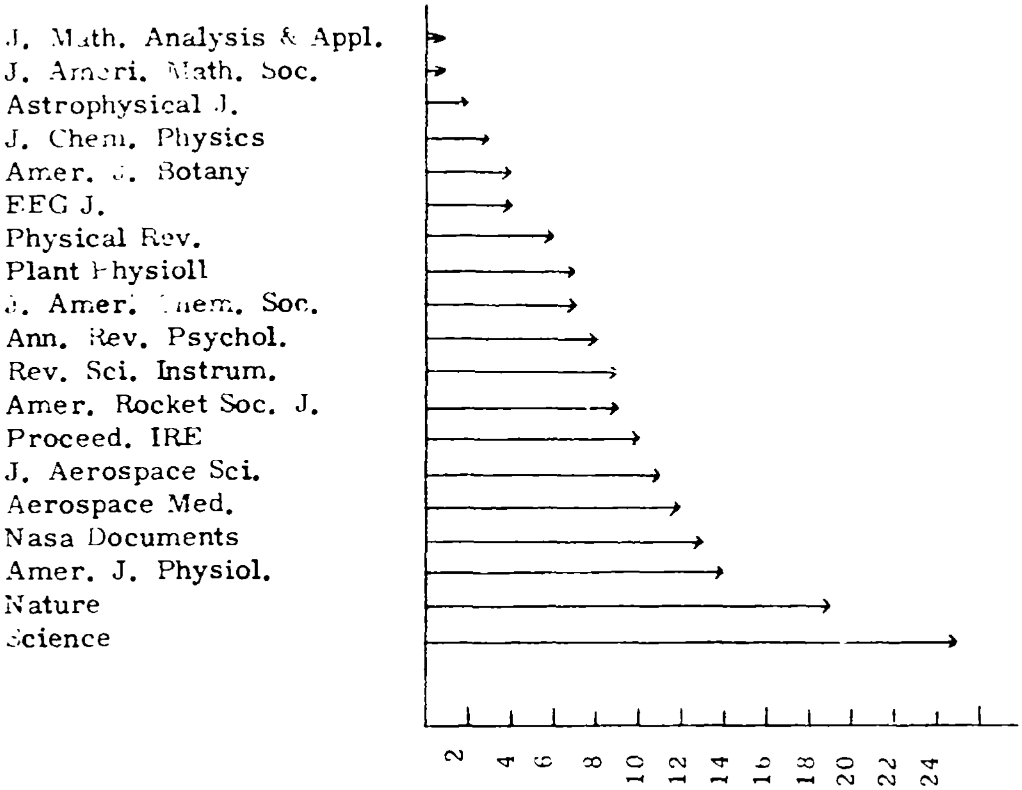
    One response listed the university library as fair, but reported that a nearby library available to him was excellent.

22. Would you please indicate with a check which of the following journals you regularly use as current information sources?

The summary of reading habits is in Figure 4 and Table IV. Figure 4 shows the frequency distribution of each periodical listed in question 22. Table IV summarizes additional periodicals added by respondees to the list in question 22, and in questions 7, 8, and 10. Table V provides a list of periodicals which are

*median of those responding.

Figure 4
Reading List from Question no. 12.



used by the respondees for publications and for reading. Table V is based on questions 7, 8, 10, and 22.

TABLE IV

Additional reading list

ACM Comm.
ACM J.
Amer. Biol. Teacher
Amer. Insti. Chem. Engnr. J.
Amer. J. Clin. Nutrition
Amer. J. Pathology
Amer. Math. Monthly
Ann. Rev. Microbiol.
Arch. Microbiol.
Astronautics and Aerospace Engnr.
Atomics
Aviat. Wk. & Space Techn.

Biochem.
Biochem. Biophys. Acta
Brit. Computer J.
Bull. Atomic Scientists

Circulation
Cospar - Space Science

Dev. in Industr. Microbiol.
EEG Journal
Experientia
Exp. Cell Res.
Exp. Neurol.

Fed. Proceed.

Industr. Engnr. Chem.

J. Appl. Physics
J. Cell Biol.
J. Exp. Bot.
J. Nutrition.
J. Theor. Biol.

Math. of Computers

Neurology
Numerische Mathematic
Nutrition Abstr. & Rev.
Nutrition Rev.

Okla. Acad. Sci. Proceed.

Percept. & Motor Skills
Plant & Cell Physiol.
Proc. 5th IBM Symposium
Proc. Nat. Acad. Sci.

SIAM J. (Soc. Ind. Appl. Math.)
SIAM Rev.
Steroids

Trans. Finn. Acad. Sci.
Trans. Soc. Rheology

TABLE V

A composite list of periodicals which are used by the respondees for publications and for reading.

	Publish	Read
ACM Comm.	X	X
ACM Journal	X	X
Advances in Cryogenic Engineering	X	X
Aerospace Medicine	X	X
American Biology Teacher	X	X
American Institute of Chemical Engineers Journal	X	X
American Journal of Botany	X	X
American Journal of Cardiology	X	X
American Journal of Clinical Nutrition	X	X
American Journal of Pathology	X	X
American Journal of Physiology	X	X
American Mathematical Monthly	X	X
American Rocket Society Journal	X	X
Annual Reviews of Microbiology	X	X
Annual Reviews of Psychology		X
Archiv. fur Mikrobiolgie	X	X
Astronautics & Aerospace Engineering	X	X
Astrophysical Journal		X
Atomics	X	X
Aviation Week & Space Technology	X	X
Biochemica et Biophysica Acta	X	X
Biochemistry	X	X
Biophysical Journal	X	X
Blood	X	X
British Computer Journal	X	X
Bulletin of Atomic Scientists	X	X
Circulation	X	X
Cospar-Space Science	X	X
Crop Science	X	X
Developments in Industrial Microbiology	X	X

	Publish	Read
EEG Journal	X	X
Experientia	X	X
Experimental Cell Research	X	X
Experimental Neurology	X	X
Federal Proceedings	X	X
Industrial and Engineering Chemistry	X	X
Journal of Aerospace Medicine		X
Journal of American Chemical Society		X
Journal of American Institute of Chemical Engineering	X	X
Journal of American Mathematical Society		X
Journal of Applied Physics	X	X
Journal of Bacteriology	X	X
Journal of Comparative Biochemistry and Physiology	X	X
Journal of Cell Biology	X	X
Journal of Chemical Physics		X
Journal of Experimental Botany	X	X
Journal of Mathematical Analysis and Application		X
Journal of Molecular Biology	X	X
Journal of Nutrition	X	X
Journal of Physical Chemistry	X	X
Journal of Theoretical Biology	X	X
Mathematics of Computers	X	X
Nature	X	X
Neurology	X	X
Numerische Mathematic	X	X
Nutrition Abstracts and Reviews	X	X
Nutrition Reviews	X	X
Perceptual and Motor Skills	X	X
Physical Reviews		X
Plant and Cell Physiology	X	X
Plant Physiology	X	X

	Publish	Read
Proceedings of the Fifth IBM Symposium	X	X
Proceedings of IRE		X
Proceedings of the National Academy of Science	X	X
Proceedings of the Oklahoma Academy of Science	X	X
Review of Scientific Instruments	X	X
Science	X	X
Society for Industrial Applied Mathematics Journal	X	X
Society for Industrial Applied Mathematics Review	X	X
Steroids	X	X
Transactions of the Finnish Academy of Science	X	X
Transactions of the Society of Rheology	X	X